Abstract

Turbulence plays a key role in most of the processes related to open-channel flows, e.g. rivers, tidal channels, irrigation canals and waterways. For instance, the transport and mixing of substances, the scour around submerged hydraulic structures, and the design of more performing hydro-kinetic turbine are some of the fields that benefit from a better understanding of turbulent properties in open-channel flows.

Among the various coherent structures that populate wall-bounded flows, Large- and Very-Large-Scale Motions (LSMs and VLSMs) are attracting significant scientific interest, not only from a merely academic perspective but also for their practical implications. Although dynamics and evolution of LSMs and VLSMs have been investigated in so-called canonical wall-flows (i.e. boundary layer, pipe and closed-channel flow), what happens to them in open-channel flows has been overlooked so far. In order to investigate the scaling of such large scale structures, novel experiments were carried out at the Giorgio Bidone Hydraulic Laboratory (Politecnico di Torino) where turbulent open-channel flows could be generated in a large-scale flume facility with and without the presence of collinear waves. The idea of perturbing open-channel flows with waves steams from the fact that waves and currents coexist in many environments and hence their interaction is relevant for many of the previously mentioned engineering applications. Moreover, gravity waves can be interpreted as perturbations whose effects can clarify issues related to turbulence in more canonical (i.e. without waves) open-channel flows. Longitudinal and vertical velocity components were measured at a high sampling frequency using a 2-D Laser Doppler Anemometer (LDA).

The first set of experiments was devoted to investigating the scaling of LSMs and VLSMs in absence of waves. Results indicate that, contrary to other

wall flows, in smooth-bed open-channel flows the presence of both LSMs and VLSMs is detectable from 1-D pre-multiplied spectra even at relatively low values of the von Kármán number Re_τ. Moreover, the spectral footprint of such scales is present across the entire depth of the investigated flows, whereas, in closed-channels, pipes and boundary layers, is limited to 60% of their vertical extension. Results also confirm that, while LSMs' wavelength follows the same scaling as reported for other wall flows, VLSMs' wavelength depends strongly on the aspect ratio of the flow.

In the second set of experiments, a benchmark open-channel flow was perturbed with collinear gravity waves with varying wave amplitude and frequency. From the velocity signal time-series, the wave and turbulent components were extracted using the Empirical Mode Decomposition (EMD) technique. When the appropriate outer velocity and length scales were employed, it was found that the flows exhibited two distinct regions: (i) a current-dominated flow region near the bed, where the turbulence shares many analogies with that typical of wall-flows; (ii) a wave-dominated flow region, where turbulence is fed by a Langmuir-type mechanism near the free-surface. Within the current-dominated flow region, the longitudinal turbulent intensities are weakly affected by the passage of the gravity waves, whereas the vertical turbulent intensities are strongly damped. This damping is more evident as the vertical wave strength (wave amplitude times wave frequency) increases with respect to the shear velocity of the current. From the spectral analysis, it is argued that the VLSMs presence vanishes when the wave strength exceeds a certain value, likely because the orbital wave motion inhibits the trigger mechanism for VLSMs. Conversely, in the wave-dominated flow region, new spectral peaks at wavelengths commensurate to those normally associated with LSMs and VLSMs become visible as the wave steepness increases. It is indeed speculated that these long structures are Langmuir-type cells.