Experimental Investigation of the Turbulent Boundary Layer Over Rough Young Wavy Water Surface

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Waves created by steady wind form a random, multi-scale, three-dimensional, moving rough surface. The unsteady roughness elements are constantly altering the turbulent airflow at the close vicinity of the water surface. Due to this complicated feedback between the airflow and waves, the resultant spatially-evolving boundary layer over these kind of surfaces is extremely challenging to understand. Nevertheless, it was recently found that the boundary layer overlying young wind waves maintains wall similarity when the equivalent sand grain roughness height is defined as the RMS of the local surface elevation[1]; this was evident even in the presence of underneath water current although the air turbulence completely differ[2]. We now extend these studies and gain a profound insight into the spatially evolving boundary layer. Experiments are conducted at Tel-Aviv 5 m long wind-wave facility. For wavelengths encountered in this study, the water depth maintains deep-water conditions; the airflow at the inlet of the section is uniform. The 2-D turbulent velocity components (u, w) are measured using x-shaped hot film, and the mean horizontal velocity is measured by a Pitot tube (ref. 3). The water surface are illuminated by a green laser sheet aligned with the hot film (figure 1c); instantaneous surface elevation wave steepness are captured at similar frame rate as the turbulence. We gain a profound insight into the unsteady evolving boundary layer by analyzing the streamwise variance of the higher-order turbulence statistics[4]; valuable information is given concerning the transport of Reynolds stress, turbulent events and coherent structures.

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[1] Geva et al., *J. Fluid Mech.*, **394** (2022).
[2] Kumar et al., submitted to *Int. J. Heat and Fluid Flow* (2023).
[3] Zavadsky & Shemer, *J. Geophys. Res.*, **117** (2012).
[4] Yuan & Piomelli., *J. Fluid Mech.*, **760** (2014).

Figure 1: The turbulent boundary layer over wind waves: (a) schematic illustration of the spatially evolving air-water system. (b) Realistic wind-wave field with airflow illustration. The image was taken at the Tel-Aviv wind-wave facility at maximum wind velocity U_0=8.9 m/s. Experiment were performed at four wind velocities U_0=5.5, 6.6, 7.8 and 8.9 m/s at several downstream loactions along the test section. (c) Detection of the inatantanous water surface.