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AMPLITUDE MODULATED NEAR-WALL CYCLE IN A TURBULENT BOUNDARY LAYER UNDER AN ADVERSE PRESSURE GRADIENT

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Nowadays, it is widely accepted that significant part of wall turbulence consist of the coherent vortical motion or coherent structures. Theodorsen (1952) proposed model of hairpin vortex, as a simple flow structure that explains existence of the low-speed streamwise streaks inducing the ejection event of the near-wall fluid into higher part of boundary layer. Adrian et al. (2000) proposed the concept of hairpin packet, according to which a number of hairpins are aligned in the stock in the streamwise direction. In such model long low-speed streak is induced by the heads and between the legs of consecutive hairpin vortices. Outside hairpin legs exist also high speed flow regions called sweeps. These long low- and high-speed streaks have been observed by Hutchins and Marusic (2007) who call them “superstructure” events. Mathis et al. (2007) have found, near the wall for high Reynolds number zero pressure gradient (ZPG) turbulent boundary layers (TBLs), the existence of coupling (modulation) between large-scale component of the velocity signal (referring to the superstructure events) and small-scale signal component. Marusic et al. (2011) observed that this effect is enhanced for high values of the outer peak of velocity fluctuation profile.

The paper shows that for the low Reynolds number flow $Re_\tau \approx 1000$ and for APG conditions the similar outer peak in velocity fluctuation profile is present, which implies the possibility of strong coupling between both scales. In Fig. 1 iso-contours of the energy spectra as a function of the scale and the y^+ are presented. The graphs show iso-contours of wavelet energy spectra E_W, scaled by the friction velocity. Left side figures (Fig 1a and c) present spectra in the function of the length scale, while the right side figures (Fig 1b and d) in the function of the time scale. The first peak, marked by a cross, and corresponding to the small-scale component is clearly visible for both zero and adverse pressure gradient. On the other hand, the outer peak, marked by a triangle, exist only for APG flow region (Fig 1c and d). It is observed for the location $y/\delta = 0.12$ and for the length scale $\lambda_x = 1 \div 2\delta$. The scale separation of the inner and outer peak is small in our case in comparison with the results presented by Mathis et al. (2007), however, the outer peak is clearly seen (Fig. 1). These results provided the basis for conducting the modulation analysis.

The analysis showed that for low Reynolds number flow the APG has highly comparable influence on the near wall turbulence production cycle, as observed for ZPG flow at high Reynolds number. As a result of preformed investigations a simple model of the large-scale structure was proposed. This model explains the reason for the increased angle of movement of vortical structures within the bursting process, which was observed by Dróżdż and Elsner (2011).

The knowledge about the effect of modulation in the adverse pressure gradient wall bounded flow could be very useful as such conditions occur in many engineering applications.

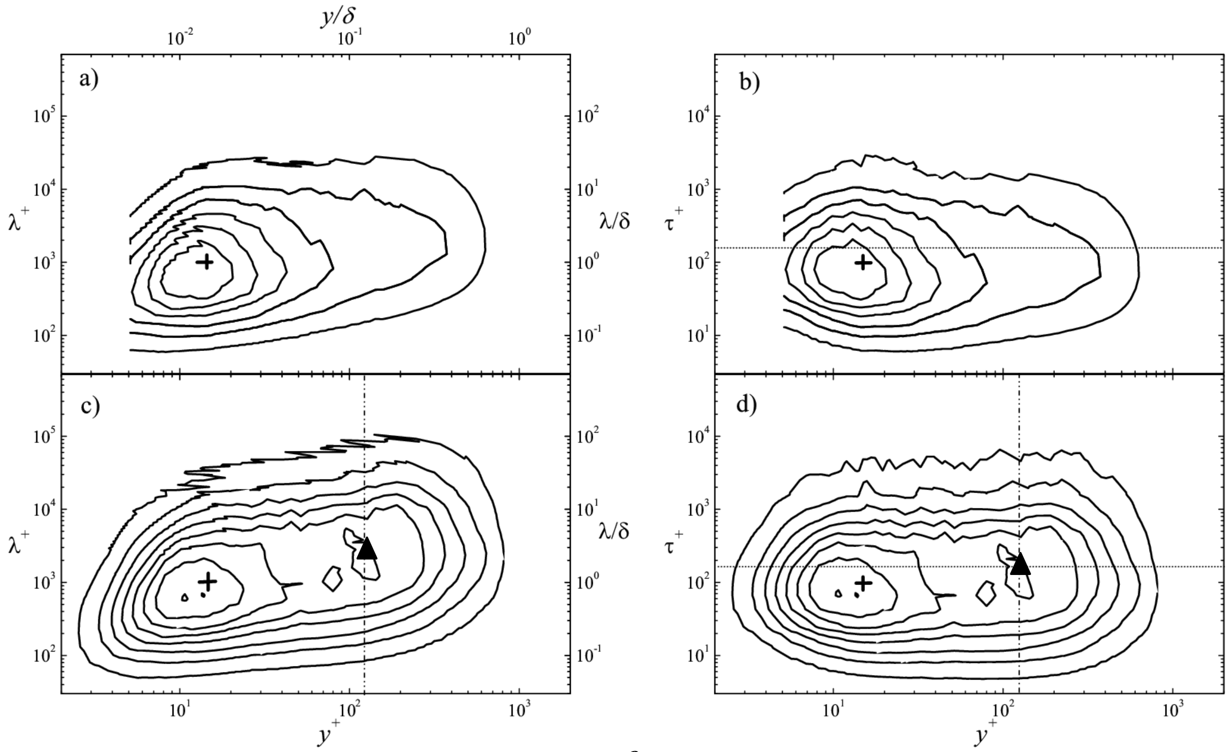

Fig. 1. Iso-contours of the wavelet energy spectra E_W/u_τ^2 across boundary layer thickness for ZPG and APG conditions ($Sg = 0.185$, $Sg = 0.597$) in function of: a) length scale (ZPG); b) time scale (ZPG); c) length scale (APG); d) time scale (APG). Contour levels are form 0.3 to 2.4 in steps of 0.3. "+" points the inner peak location ($y^+ = 15$, $\lambda_x^+ = 1000$). The horizontal dot lines show the location of the spectral filter, while vertical dot-dashed lines shows the location of the outer peak in the APG flow ($y/\delta = 0.12$, $\lambda_x/\delta = 1 \div 2$).

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