Sixth HRLM Symposium, 26-28 September 2016, Strasbourg University, France

Session: Wall-Modelled LES (WMLES)

On the convection velocity of wall-bounded turbulence resolved by ZDES mode III at $Re_\theta = 13\,000$

Nicolas Renard & Sébastien Deck

ONERA, The French Aerospace Lab

Wall-modelled Large Eddy Simulation (WMLES) may resolve turbulent fluctuations in the outer layer of attached boundary layers when such a description level is needed (mild flow separation with upstream history effects, dynamic loading and aeroacoustics predictions…). The inner layer dynamics, whose resolution cost is prohibitive at high Reynolds numbers, is modelled ([1]). One possible WMLES strategy is a near-wall RANS / outer LES treatment in line with hybrid RANS/LES methods suited for complex geometries and flows. The zones of interest for LES and the zones were a RANS description is sufficient may be defined by the user, as for instance in Zonal Detached Eddy Simulation (ZDES, [2]), with its mode III suited for WMLES ([3]). Mean skin friction predictions within 5% of the Coles-Fernholz correlation are achieved in a flat-plate zero-pressure-gradient boundary layer with $\Delta x^+=200$ and $\Delta z^+=100$ resolutions by properly choosing the RANS/LES interface wall distance, *e.g.* $y = 0.1\,\delta$ or $y^+ = 3.9\,Re_\tau^{1/2}$ (fig. 1). The latter interface position provides in addition a higher resolved fraction of C_f ([4]). The physical relevance of the resolved turbulent content (see fig. 2) may be assessed from streamwise velocity spectra (fig. 3). Comparing with experimental data ([3]) suggests an excess of streamwise velocity fluctuations right below the RANS/LES interface, especially with the $3.9Re_\tau^{1/2}$ interface.

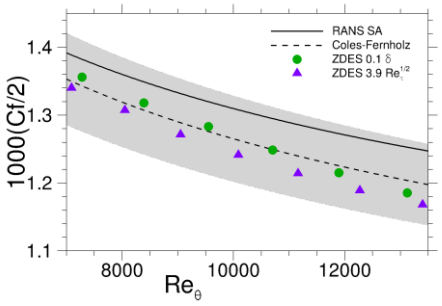

Fig. 1 Mean skin friction coefficient evolution

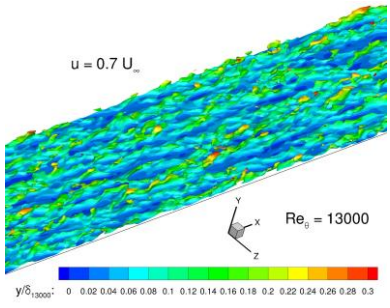

Fig. 2 Streamwise velocity isosurface coloured by wall distance near $Re_\theta = 13\,000$ (ZDES, 3.9 $Re_\tau^{1/2}$ interface)

Session: Wall-Modelled LES (WMLES)

To better understand whether the fluctuations are physically relevant or whether they are spurious artefacts caused by the WMLES strategy, their frequency-dependent convection velocity is determined here (see fig. 4) by a spectral evaluation method introduced in [5] in a Wall-Resolved LES case and based on the following equation:

$$U_C(f) = -\frac{2\pi f S_{uu}(f)}{\mathrm{Im}(S_{u\partial_x u}(f))} \tag{1}$$

Two different interface locations will be compared, with special attention paid to the location of the $U_c = \langle u \rangle$ line (analogous to the critical layer in resolvent analysis [6]) relative to the spectral energy sites (fig. 3) in order to discuss the physical nature of the fluctuations.

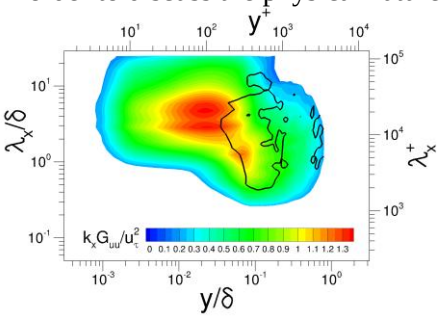

Fig. 3 Streamwise velocity spectrum, $Re_\theta = 13\,000$ (ZDES, 3.9 $Re_\tau^{1/2}$ interface, solid line $U_c = \langle u \rangle$)

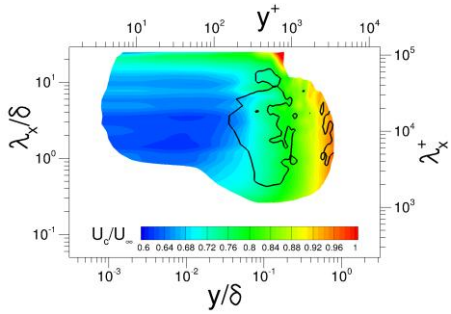

Fig. 4 Convection velocity, $Re_\theta = 13\,000$ (ZDES, 3.9 $Re_\tau^{1/2}$ interface, solid line $U_c = \langle u \rangle$)

References

[1] U. Piomelli, Wall-layer models for large-eddy simulations, *Prog. in Aerosp. Sc.*, 44 (2008)

[2] S. Deck, Recent improvements in the Zonal Detached Eddy Simulation (ZDES) formulation, *Theor. & Comp. Fl. Dyn.*, 2012, 26, 523-550

[3] S. Deck, N. Renard, R. Laraufie & P. Sagaut, Zonal Detached Eddy Simulation (ZDES) of a spatially developing flat plate turbulent boundary layer over the Reynolds number range 3150 ≤ Re_θ ≤ 14000, *Phys. of Fl.*, 2014, 26, 025116

[4] N. Renard & S. Deck, Improvements in Zonal Detached Eddy Simulation for Wall Modeled Large Eddy Simulation, *AIAA Journal*, 2015, 53, 3499-3504

[5] N. Renard & S. Deck, On the scale-dependent turbulent convection velocity in a spatially developing flat plate turbulent boundary layer at Reynolds number Re_θ = 13000, *J. of Fl. Mech.*, 2015, 775, 105-148

[6] A. S. Sharma & B. J. McKeon, On coherent structure in wall turbulence, *J. of Fl. Mech.*, 2013, 728, 196-238