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Session:

Grey-area mitigation using commutation terms at the interfaces in hybrid RANS-LES modeling

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Introduction

Since the time-averaging filter used in RANS and the spatial filter used in LES do not commute, additional terms arise in the hybrid RANS-LES equations at the RANS-LES interface (Hamba, 2011). In order to mitigate the grey-area between the RANS and the LES regions, the effect of the commutation terms at the RANS-LES interfaces are investigated for fully developed turbulent channel flow and spatially developing turbulent boundary layer flow using a zonal hybrid RANS-LES approach based on a low-Reynolds-number k-ω model (Arvidson et al., 2014).

The commutation term is included in the transport equations for k and ω. By including this term at the RANS-LES interface, we formulate a modeling approach that automatically adapts the turbulent viscosity, without any empirical constants, to the modeling mode, i.e. RANS or LES. In embedded LES when switching from RANS to LES, with a RANS-LES interface normal to the wall, the commutation terms are only added in the RANS-to-LES direction across the interface. At the wall-parallel RANS-LES switch, the commutation terms are added either in both directions across the interface, i.e. from RANS-to-LES and LES-to-RANS, or only in the direction from RANS-to-LES.

Results

The time-averaged commutation and the production terms in the turbulent kinetic energy equation are shown in Fig. 1 (a) for fully developed turbulent channel flow at Re_τ=8000. The RANS-LES interface is located at y^+=250. Different interface locations are presented in the full paper. By adding the commutation term in both directions at the RANS-LES interface, an overall increased production of k is given in the interface region which delays the development of resolved stresses as seen in Fig. 1 (b) and amplifies the log-layer mismatch (not shown here). A weak effect on the resolved stresses and the log-layer (not shown here) is observed when the commutation term is applied only in the RANS-to-LES direction across the interface.

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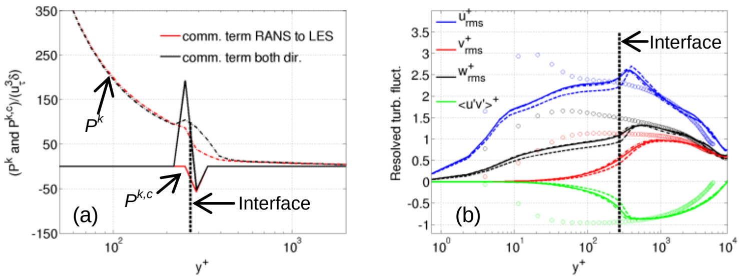

Fig. 1 Channel flow. (a) Commutation ($P^{k,c}$) and production (P^{k}) terms in the k-equation. (b) Resolved turbulent fluctuations. ——: no commutation term; –·–: commutation term RANS-to-LES; - - -: commutation term in both directions; ∘: DNS data for Re_τ=5200 (Lee & Moser, 2015).

The spatially developing boundary layer flow, with an inlet Reynolds number Re_θ=5000, is simulated in the context of embedded LES. At the inlet boundary, RANS data from a precursor PDH-LRN k-ω simulation is applied. Commutation terms are added at the inlet to adapt k and ω to LES subgrid scale levels and synthetic turbulent fluctuations are imposed. The commutation term is also added at the wall-parallel RANS-LES interface in the k- and ω-equations. Fig. 2 (a) shows the commutation term in the k-equation at the inlet which has a strong effect on the production of k immediately downstream of the inlet. The effect of the commutation term acting in the wall-normal direction is seen at the wall parallel RANS-LES interface located at y^+=200. As in channel flow, the most significant effect is observed by using the commutation terms in both directions across the wall-parallel RANS-LES interface. Adding the commutation term only in the RANS-to-LES direction across the interface gives a minor effect compared to the RANS-LES switch where no commutation terms are added. The flow reaches a fully developed state at a distance of (3-4)δ downstream of the inlet as seen in the skin friction shown in Fig. 2 (b).

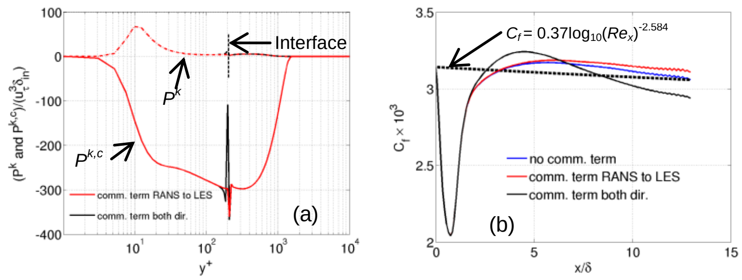

Fig. 2 Boundary layer. (a) Commutation ($P^{k,c}$) and production (P^{k}) term at the grid plane adjacent to the inlet. (b) Skin friction downstream of the inlet.