T-PITM : a consistent formulation for seamless RANS/TLES coupling

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Résumé :

L'utilisation en LES de filtres temporels plutôt que spatiaux offre un cadre formel consistant pour la modélisation hybride RANS/LES continue (devenant ainsi RANS/TLES). Un tel modèle hybride est présenté, le T-PITM, adaptation de la méthode PITM (Partially Integrated Transport Model) au cadre du filtrage temporel, basé sur la résolution d'équations de transport pour les tensions de sous-filtre et la pondération elliptique pour la prise en compte des effets de paroi.

Abstract :

Using temporal filtering in LES rather than spatial filtering provides a consistent formalism for seamless hybride RANS/LES (thus becoming RANS/TLES). Such an hybrid model is presented, the so-called T-PITM, which is the adaptation of the PITM (Partially Integrated Transport Model) to the temporal filtering framework, based on transport equations for the subfilter stresses and elliptic blending to account for wall effects.

Mots clefs : Hybrid, TLES, PITM, elliptic blending, elliptic relaxation, channel flow

1 Consistency and Invariance

A multitude of unsteady low-cost strategies have gained prominence over the last decade. Some of these models can be described as seamless hybrid RANS-LES models, in the sense that the computation progressively transitions from a RANS model in some regions of the flow, particularly in the near-wall zones, to an LES in other regions where explicit computation of the large-scale structures is required. In statistically homogeneous flows, such a model can be seen as an LES with a filter width Δ continuously going to infinity or, equivalently, as an LES with a cutoff wavenumber κ_c continuously going to zero, which is the limit corresponding to the RANS approach. However, the majority of flows of practical relevance are inhomogeneous, and in that case such models suffer from an important conceptual weakness due to the inherently different concepts underlying LES and RANS models : the former give spatially filtered fields ; whereas, the latter give long-time averaged fields. In an analogous fashion, it is possible to construct in statistically steady (stationary) flows, a model that can be seen as a *Temporal Large-Eddy Simulation* (TLES) with a filter width Δ_T continuously going to infinity or, equivalently, as a TLES with a cutoff frequency ω_c continuously going to zero, which is the limit corresponding to the RANS approach [1]. Within the TLES approach, an explicit filter can be defined that ensures the Galilean invariance of both the filtered variables and the associated transport equations. This, coupled with the correct limiting behavior associated with the temporal filter Δ_T, forms the basis for consistently defined variables that can represent both filtered or averaged field variables.

2 Hybrid Model : Temporal PITM (TPITM)

Since the form-invariance of the filtered and averaged Navier-Stokes equations is well-known, the delimiting between filtered and averaged fields rests in the subfilter scale modeling and the associated spectral cutoff. This formalism can be readily coupled to an adaptation of the Partially Intergated Transport Model (PITM) [2, 3] to a temporal PITM (TPITM) model. The result is a hybrid method that incorporates both a spectral cutoff associated with the inclusion of filtered stress and a system of transport equations used to govern the subfilter scales (SFS). In this case, transport equations for the subfilter stresses and the dissipation rate are used analogous to the familiar second-moment closure RANS system but with closure predicated on length and time scales consistent with a filtered field with frequency cutoff ω_c rather than closure predicated on equilibrium turbulence. Additionally, the resulting equation system within this TPITM framework can be amended in order to account for nonlocal wall-blockage by employing the elliptic blending methodology [4, 5], a simplified formulation of the elliptic relaxation methodology [6]. An example of the partitioning of the turbulent energy

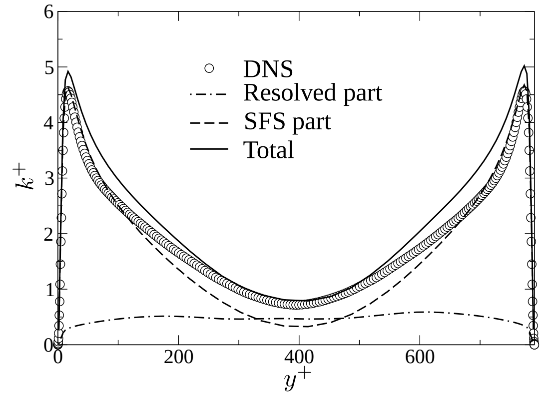

FIG. 1 – Contributions of the resolved and modelled flow fields to the turbulent energy.

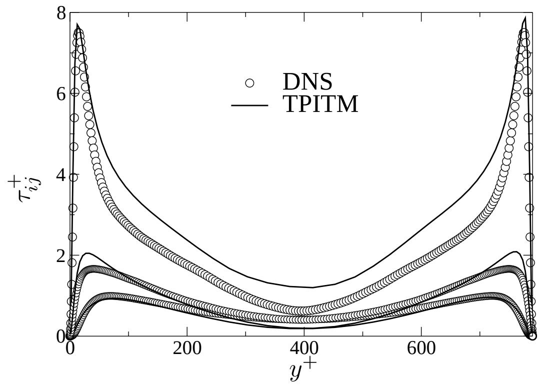

FIG. 2 – Diagonal Reynolds stresses.

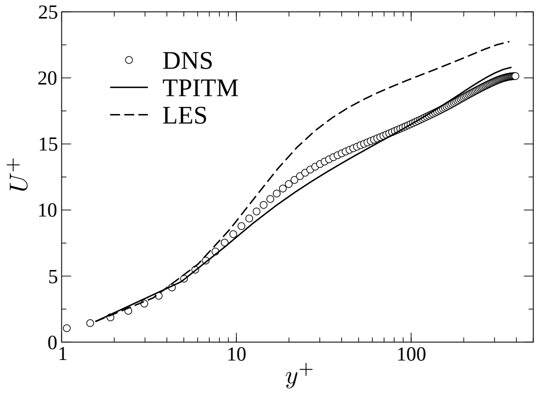

FIG. 3 – Mean velocity profiles. Comparison with results obtained on the same coarse mesh using the dynamic Smagorinski model.

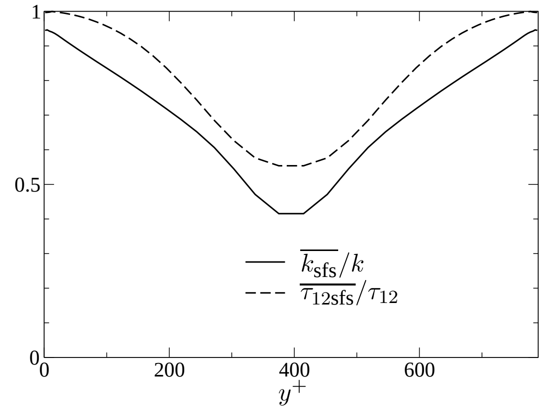

FIG. 4 – Rate of resolved energy and shear-stress.

among the resolved and subfilter scales is shown in Fig. 1 for the case of a channel flow at $Re_\tau = 395$, in comparison with DNS [7]. This figure and Fig. 4 show that the subfilter kinetic energy is 90% of the total kinetic energy indicating a RANS-type behavior in the vicinity of the wall, but decreases to 40% near the center of the channel suggesting a very large-eddy simulation behavior. Moreover, Fig. 4 shows that the 10% of resolved energy in the near-wall region are not contributing to the shear-stress, which indicates that they are the footprint of the inactive motions induced by the outer layer. Figs. 2 and 3 show the satisfactory reproduction by the model of the Reynolds stress anisotropy, and of the mean-velocity profile on a mesh much too coarse for standard LES.

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