8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

INTERFACE ISSUES IN LES/RANS COUPLING STRATEGIES: LOCATION, VARIABLES EXCHANGE AND TURBULENCE LEVEL ADJUSTMENT

Björn Kniesner and *Suad Jakirlic

Chair of Fluid Mechanics and Aerodynamics, Darmstadt University of Technology
Petersenstr. 30, 64287 Darmstadt, Germany
b.kniesner@sla.tu-darmstadt.de, s.jakirlic@sla.tu-darmstadt.de

Key Words: *Zonal LES/RANS hybrid model, Smagorinsky/1-eq. SGS models, eddy-viscosity RANS models, validation/applications, flow separation and reattachment.*

ABSTRACT

The RANS (Reynolds-Averaged Navier-Stokes) methods represent the mainstay of the contemporary industrial Computational Fluid Dynamics (CFD). These methods describing well the general character of the flow are especially affordable in attached flow regions (near-wall). However, due to the time averaging, the unsteady flow effects originating from the large-scale dynamics are captured poorly or not at all. The LES (large-eddy simulation) method, by which the large turbulence eddies are resolved directly and the influence of the residual motion is modelled, are regarded as a remedy for all RANS weaknesses and accordingly as the future industrial standard. This method is capable to capture the most important part of the energy spectrum and the flow physics in general. However, the price for this are multiply increased computational costs, which are mainly determined by the fact that the near-wall region has to be resolved appropriately fine. At this point hybrid LES/RANS strategy comes into play. Its objective is to combine the advantages of LES and RANS in order to provide a method which is able to correctly capture the flow unsteadiness but at affordable costs.

A computational strategy coupling near-wall, eddy-viscosity-based RANS models with LES in a two-layer Hybrid LES/RANS (HLR) scheme is proposed in the present work. The RANS model covers the near-wall region and the LES model the remainder of the flow domain. Two different subgrid-scale (SGS) models in LES were considered, the Smagorinsky and the one-equation model (for the residual kinetic energy, Yoshizawa and Horiuti, 1985), combined with different eddy-viscosity, ε-equation-based RANS models. Hereby, two versions of the ε equation, one using the "isotropic" ($\tilde{\varepsilon}$, Launder and Sharma, 1974; Chien, 1982) and the other the "homogeneous" (ε^h, Jakirlic and Hanjalic, 2002) energy dissipation rates were employed. In addition, the anisotropy-reflecting, elliptic-relaxation-method-based, 4-equation model (k-ε-ζ-f; with ζ denoting the ratio of the normal-to-the-wall Re-stress component to the kinetic energy of turbulence $\overline{v^2}/k$) of Hanjalic et al. (2004) was also applied. The equations of motion are solved in the entire solution domain irrespective of the flow sub-region (LES or RANS) sharing the same temporal resolution. Depending on the flow zone, the hybrid model implies the determination of the turbulent viscosity ν_m either from the RANS or

from the LES formulation. Key questions concerning the coupling of both methods are closely connected to the treatment at the interface separating both sub-regions. Hereby, great importance is attached to simplicity, efficiency and applicability to complex geometries. The exchange of the variables across the LES/RANS interface was adjusted by implicit imposition of the condition of equality of the modelled turbulent viscosities (by assuming the continuity of their resolved contributions across the interface), enabling a smooth transition from RANS layer to the LES sub-region, Fig. 1-left. Here, the solutions of the model equations for k_{RANS} and ε_{RANS} merge with the k_{SGS} and ε_{SGS} values estimated in line with the Masson and Callen's (1986) proposal for the case of the Smagorinsky model. In addition, a special forcing technique, which compensates the loss of information due to strong damping in the RANS region by creation of artificial and correlated fluctuations, was applied at the interface, Fig. 1-right. The last issue is the utilisation of a self-adjusting interface in the course of the simulation. The control parameter k^* representing the ratio of the modelled (SGS) to the total turbulent kinetic energy in the LES region, averaged over all grid cells at the interface on the LES side, is adopted in the present work. Its nominal value amounts to 20%. Several options with respect to the positioning of the interface are tested, Fig. 2.

The method was intensively validated against the available DNS, fine- and coarse grid LES and experiments in turbulent flow (and heat and mass transfer) in a fully-developed channel flow at Re number $Re_m \approx 24000$ (Abe et al., 2004), over a backward-facing step at a low (Kasagi and Matsunaga, 1995; Yoshioka et al., 2001) and a high Re number (Vogel and Eaton, 1985), periodic flow over a series of 2-D hills (Fröhlich et al., 2005), high Re number flow over a 2-D hump including separation control (Greenblatt, 2004; Fig. 2), flow over a 3-D hill (Simpson et al., 2002) and in different, tubo-annular and single-annular swirl combustor configurations (Palm, 2006; Gnirss et al., 2006).

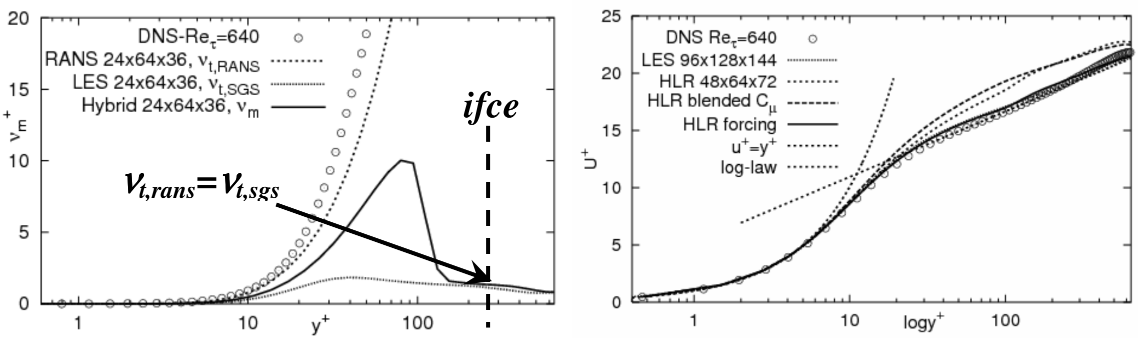

Figure 1: Variation of modelled turbulent viscosity across the LES/RANS interface (ifce, left) and effects of different variable exchange techniques on mean velocity (right) in a fully-developed channel flow

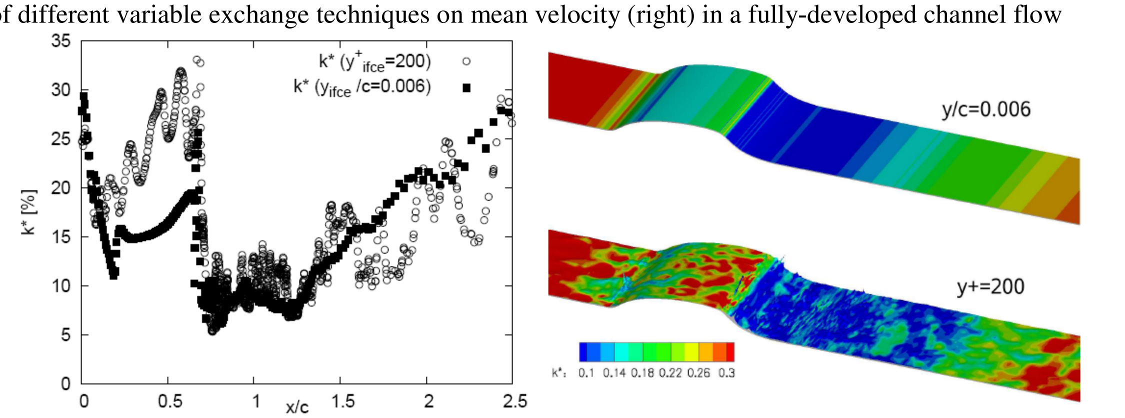

Figure 2: Interface surfaces at y/c=0.006 and y^+=100 coloured by k*-values (right) and direct comparison of the k*-evolution along the interface (left; the section corresponds to the mid-span position)