RANS-based modelling of turbulence in LES-related flow-simulation methods

S. Jakirlic,
C.-Y. Chang, G. John-Puthenveettil, B. Kniesner, L. Kutej, I. Maden, R. Maduta, M. Ullrich

Institute of Fluid Mechanics and Aerodynamics / Center of Smart Interfaces
Technische Universität Darmstadt, Alarich-Weiss-Straße 10, D-64287 Darmstadt, Germany
s.jakirlic@sla.tu-darmstadt.de

ABSTRACT

All turbulent flows are unsteady by nature. Even if the mean flow can be regarded as steady (and e.g. two-dimensional) the turbulence is always unsteady (and three-dimensional). In some simple attached flows, the mean flow and corresponding turbulence structure can be correctly captured by using conventional models employed in (steady/unsteady) RANS (Reynolds-Averaged Navier Stokes) framework. However, in configurations featured by flow separated from curved continuous walls (characterized by intermittent separation region) the fluctuating turbulence associated with the separated shear layer has to be appropriately resolved in order to capture even the mean flow properties. At this point, the hybrid LES/RANS methods come into play. Their aim is to combine the advantages of both RANS and LES methods in order to provide a computational procedure that is capable to affordably capture the unsteadiness of the flow. Following eddy-resolving methods are in focus:

A **zonal, two-layer hybrid LES/RANS method**, with a differential near-wall eddy-viscosity model resolving the wall layer and the conventional LES the core flow. Special attention was devoted to the coupling of both methods, the issue being closely connected to the treatment at the interface separating RANS and LES 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 modeled 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. Next important issue is the utilization of a self-adjusting interface position in the course of the simulation. A control parameter representing the ratio of the modeled (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.

VLES (Very Large-Eddy Simulation) **and PANS** (Partially-Averaged Navier Stokes) - **seamless, variable-resolution hybrid LES/RANS models**. In both methods a four-equation, anisotropy-resolving eddy-viscosity model, based on the elliptic-relaxation method was employed to mimic the sub-scale model seamlessly in the entire flow domain. Whereas the destruction term in the equation governing the scale-supplying variable is appropriately modelled in the PANS framework, the VLES method is concerned with appropriate suppression of the turbulent viscosity in the equation of motion directly. Such actions cause turbulence level to be suppressed towards the 'sub-scale' ('sub-filter') level. Herewith, the development of the structural characteristics of the flow and associated turbulence is enabled.

An **instability-sensitive Second-Moment Closure model** for unsteady flow computations. The model scheme adopted, functioning as a 'sub-scale' model **in the Sensitized (Unsteady) RANS framework**, represents a differential near-wall Reynolds stress model formulated in conjunction with the scale-supplying equation governing the homogeneous part of the inverse turbulent time scale. The model capability to account for the vortex length and time scales variability was enabled through a selective enhancement of the production of the dissipation rate in line with the **SAS proposal** (Scale-Adaptive Simulation, Menter and Egorov, 2010) pertinent particularly to the highly unsteady separated shear layer region. In all cases considered the fluctuating velocity field was obtained started from the steady RANS results. The model proposed does not comprise any parameter depending explicitly on the grid spacing.

The predictive performances of the proposed models are intensively validated in numerous aerodynamic-type flows of different complexity featured by 2D and 3D separation. These as well as the results obtained by the consequent models application to some configurations relevant to car aerodynamics and IC engines will be presented.