COMPARATIVE ASSESSMENT OF GRID-SPACING-BASED FILTER WIDTH FORMULATIONS FOR VERY LARGE EDDY SIMULATION

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<u>*Abstract*</u>   When applying hybrid LES/RANS turbulence models the relevant filter width plays a crucial role concerning switching between different operating modes. Presently, the influence of the filter width and the choice of the corresponding criterion within the so-called VLES (Very Large Eddy Simulation) computational framework is investigated. Results obtained by using three eddy-viscosity-based background RANS (Reynolds-Averaged Navier-Stokes) models in conjunction with different filter-width formulations and two representative wall-bounded flow configurations are presented.

HYBRID TURBULENCE MODELING

In the last decades modeling approaches hybridizing appropriately different methods for turbulent flow simulations became increasingly popular. Such approaches combine the advantages of different basic modeling techniques, hence overcoming their shortcomings. These techniques are the Direct Numerical Simulation (DNS), which requires a very fine numerical grid size being of the order of the Kolmogorov scales, implying consequently large computing power, the Large Eddy Simulation (LES), which yields very good results for separated shear layer regions characterized by large-scale eddy structures and bulk flow unsteadiness, and finally the Reynolds-Averaged Navier-Stokes (RANS) models with their low computational costs.

The most popular hybrid turbulence method which has also been successfully used for many complex turbulent flows is the Detached Eddy Simulation (DES). It combines the RANS operating mode in the attached boundary layers coupled with LES in separated (detached) regions and off-wall regions in general [4]. The major weakness of DES and DES-related methods is the so-called 'grey area', an area in which the transition from RANS to LES working modes takes place, where the solution corresponds neither to pure RANS nor to pure LES [2]. This leads to non-satisfactory results for some kind of flows.

Chang [1] provides an alternative hybrid turbulence approach which resembles the Very Large Eddy Simulation (VLES) model of Speziale [5]. This model switches seamlessly between RANS and DNS modes depending on the numerical grid resolution. For this, a so-called resolution control function F_r is introduced multiplying the turbulent viscosity representing the solution of the evolution equations of turbulent quantities pertinent to the underlying RANS model formulation. By doing so, the turbulence intensity is 'rescaled'; i.e. the fully-modeled turbulence, relevant to the RANS framework, is appropriately suppressed towards the level corresponding to the residual turbulence of the VLES method. This function depends on the turbulent length scale L_c related to the spectral cut-off (coping actually with the grid resolution applied) and the integral length scale L_i ($\propto k^{3/2}/\varepsilon$):

$$F_r = min\left[1, \left(\frac{L_c}{L_i}\right)^{\frac{3}{4}}\right]. \tag{1}$$

The value of this resolution control function lies between one and zero. When F_r approaches 0, all scales are (theoretically) resolved and the VLES model behaves like a DNS. When $F_r \to 1$, as in the case of a coarser mesh, the model works as a RANS model.

In [1] and [2] it has been shown that the VLES approach is capable of achieving good predictions for a wide range of turbulent flows with less computational effort in comparison to LES.

INFLUENCE OF FILTER WIDTH ON THE RESULTS WITHIN VLES

VLES switches between DNS and RANS models depending on the ratio of turbulent viscosities associated with the unresolved scales corresponding to the LES cut-off and the 'unsteady' scale pertinent to the turbulent properties of the VLES residual mode (see equation 1). The turbulent cut-off is defined as $L_c = C_x \Delta$ with Δ being the filter width.

The filter width determines the value of the resolution control function and implies therefore a kind of 'interface' between RANS and DNS. Thus, the choice of the expression for Δ may play an important role, especially in the case of strongly anisotropic grids.

An expression which is typically employed for LES is the geometric mean

$$\Delta = (\Delta_x \Delta_y \Delta_z)^{\frac{1}{3}} \tag{2}$$

and for DES the so-called maximum criterion

$$\Delta = max\left(\Delta_x, \Delta_y, \Delta_z\right) \tag{3}$$

is used in most of the cases. Δ_x, Δ_y and Δ_z are the grid sizes in the three spatial directions.

In addition, in [6] a new subgrid length-scale for the modified DES model, the so-called improved Delayed DES (IDDES), is formulated, which is dependent on local cell sizes, the grid size in the wall-normal direction and the distance to the wall.

These three filter widths are investigated with respect to their influence on the predictions within the VLES model for three different basic RANS models: $k - \varepsilon$, $k - \omega$ and $k - \varepsilon - \zeta - f$ ([3]). As test cases a fully-developed channel flow at turbulent Reynolds number of $Re = 395$ and a separating flow over a series of axisymmetric hills, in periodic sense, at a Reynolds number of $Re = 10595$ are considered.

In Figure 1 the mean streamwise velocity profiles in the channel flow obtained with VLES using different filter widths and the $k - \varepsilon$ model as the background RANS model are compared to a DNS result. One can observe the significant influence of the filter width on the VLES results.
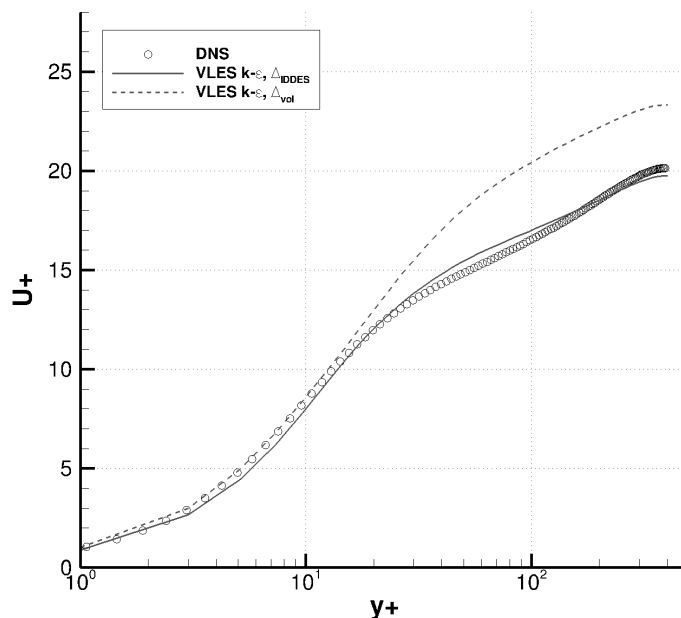

Figure 1. Comparison of mean streamwise velocity profiles for channel flow at $Re = 395$.

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