HYBRID V2F RANS/LES MODEL AND SYNTHETIC INLET TURBULENCE APPLIED TO A TRAILING EDGE FLOW

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ABSTRACT

The flow over a trailing edge is computed using two different techniques to reduce the computational costs of LES. A hybrid method designed to split the contributions of the averaged and fluctuating velocity fields is used in order to relax the near-wall mesh requirements. A synthetic method for turbulence generation is used at the inlet in order to avoid a costly precursor simulation. The methodology has been first tested on channel flows at high Reynolds numbers on coarse meshes. The results at different Reynolds numbers up to Re_τ are presented. They agree well with DNS data available in terms of mean velocities and stresses. The results for the trailing-edge flow are compared with the full LES with inlet boundary conditions from a precursor boundary layer simulation. Two cases are presented, one with a precursor simulation and one with the synthetic eddy method. The predictions of mean velocities and turbulent content agree well with the reference LES simulation.

INTRODUCTION

Large Eddy Simulation has been successfully applied to many different kinds of flows, but its use in industry has remained scarce, mainly due to the large constraint present in the mesh requirements of wall bounded flows, especially at high Reynolds numbers. For such flows, the size of the energy containing structures scales with $Re_\tau = 4000$ and hence the number of grid points required to resolve accurately the near wall eddies scales with $Re^{1.76}$ at least (unstructured grids). To circumvent this severe near wall requirement, LES can be restricted to the simulation of the outer flow eddies with a RANS like eddy viscosity model used to model the dynamics of the near wall eddies. In recent years, such hybrid methods combining RANS and LES have received increased attention from groups around the world. In an attempt to ease such computational requirements in wall bounded flows, many approaches have been suggested. One method is to use so-called "wall functions" to bridge the viscous sublayer and provide a suitable boundary condition for the wall cells (Piomelli and Balaras, 2002). This can range from a log-law approximation (Schumann, 1975) to a solution of a system of simplified equations in the near wall region (Balaras et al., 1996).

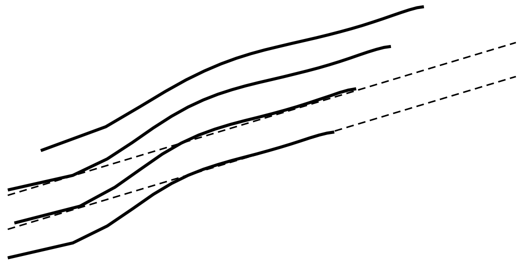
Another approach is the use of RANS equations near the wall to provide the outer layer with correct information. The main problem of this type of approach is how to connect a statistically averaged flow (RANS) with the instantaneous filtered field (LES). A way to couple the two types of flows is the Detached Eddy Simulation (DES) (Spalart et al., 1997; Travin et al., 1999) in which the turbulent lengthscale in the RANS equation is switched to a lengthscale based on the mesh filter width in order to reduce the viscosity in the separated region. Other approaches are 'zonal', in which a part of the domain is set to be computed using RANS equations and the rest is computed with LES. Examples of such types of models can be found in Davidson and Peng (2003), **?** or Hamba (2003). In the zonal approach, the treatment of the interface has always been of importance for the success of the method since the RANS information does not provide correct turbulent fluctuations. Some ways to deal with this issue are the introduction of backscatter (**?**), damping the modelled stresses (Temmerman and Leschziner, 2002), the addition of fluctuations at the LES side of the interface (Davidson and Dahlström, 2005) or the use numerical smoothing (Tucker and Davidson, 2004).

A second constraint of the LES technique has been the problem of boundary conditions, which ideally need to be time and space dependent. To reduce the cost incurred by retaining boundary conditions from precursor calculations, the development of synthetic turbulence generation methods has been the focus of many studies in recent years (Klein et al., 2003; Keating et al., 2004). These synthetic methods are able to reproduce spectra or moments of real turbulence but do not produce turbulence eddies with neither correct shape nor dynamics. Therefore the flow downstream of the inlet undergoes an adjustment as the synthetic fluctuations evolve until the correct phase information is retrieved.

In this paper we address both of these issues. First by introducing a hybrid model that uses the elliptic relaxation approach described in Laurence et al. (2004) as a RANS baseline model to be combined with the standard Smagorinsky sub-grid scale model for LES. Results for channel flows up to $Re_\tau = 4000$ in coarse meshes are presented. Secondly the case of flow over a aerofoil is computed using the a synthetic eddy method of Jarrin et al. (2006) at the inlet.

Table 1: Parameters for the channel flow calculations.

Re_τ	Cells	Δx^+	Δz^+
395	40x40x30	59	39
590	40x40x30	88	59
1100	50x50x40	140	88
2000	50x40x50	256	160
4000	64x80x64	400	200



strain rate. The two components are joined together via a blending function which relates the length scales provided by the RANS model and the LES.

$$f_b = \tanh\left(\left(C_L \frac{L_t}{L_\Delta}\right)^n\right) \qquad (2)$$

where L_t is the turbulent length scale provided by the RANS model and L_Δ is the LES filtered length scale (using $L_\Delta = C_s\Delta$). $C_L = 1$ and $n = 1.5$ are empirical constants chosen to match velocity and stress profiles at $Re_\tau = 395$ on a coarse mesh with $\Delta x^+ = 59$ and $\Delta z^+ = 39$. The subgrid-scale viscosity is calculated using the Smagorinsky (1963) model:

$$\nu_r = (C_s\Delta)^2\sqrt{2s'_{ij}s'_{ij}} \qquad (3)$$

$$s'_{ij} = \overline{S}_{ij} - \langle\overline{S}_{ij}\rangle \qquad (4)$$

The RANS viscosity is calculated from the averaged velocity field using the elliptic relaxation model of Durbin (1991) modified as in Laurence et al. (2004):

$$\nu_a = C_\mu \varphi k T \qquad (5)$$

where $\varphi = \overline{v^2}/k$ and T is the timescale given by

$$T = \max\left(\frac{k}{\varepsilon}, C_T\sqrt{\frac{\nu}{\varepsilon}}\right) \qquad (6)$$

The lengthscale L_t is computed as

$$L_t = \varphi\frac{k^{3/2}}{\varepsilon} \qquad (7)$$

The effects of the wall are introduced via elliptic relaxation on the variable f which acts as the source term in the equation of φ. The transport equations (k,ε,φ and f, see Laurence et al. (2004)) are solved using the averaged velocity field obtained from a moving average of the instantaneous field computed with equation 1.

The method has been validated for channel flows with Reynolds numbers up to $Re_\tau = 4000$ (see Figure 1). The parameters used for these calculations are listed in table 1. The RANS to LES blending is very smooth since the velocity profiles follow quite closely the log law whereas other hybrid RANS-LES methods are known to introduce an increase of velocity at the interface (see Nikkitin et al. (2000)). The meshes are too coarse for a wall resolved LES. In figure 2 the results at $Re_\tau = 395$ on the same mesh are compared with the standard Smagorinsky LES (with Van Driest damping), which overpredicts the velocity due to the underresolved prediction of the shear stress. The hybrid model improves the shear stress by adding the modelled stress based on the averaged velocity as it is shown in figure 3. The normal stresses are also improved by the hybrid method as it can be seen from figure 4 where the resulting Smagorinsky LES stresses using the same mesh are also shown. Results at a $Re_\tau = 2000$ are compared with

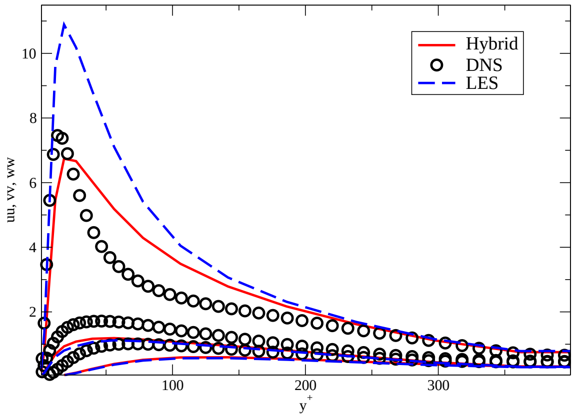


Figure 4: Normal stresses at $Re_\tau = 395$

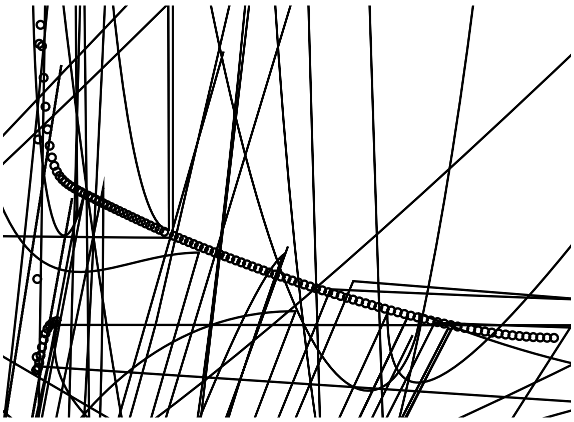
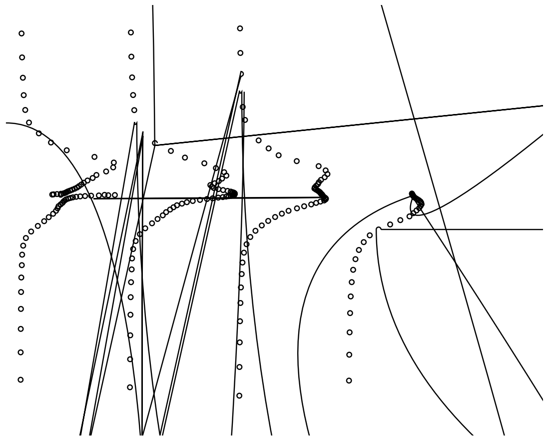


Table 2: Mesh sizes.

	Fine LES	Present
Domain size	1536x96x48	512x64x24
Δx^+,Δy^+, Δz^+	62,55,2	206,110,2
Inlet B.L. required	2x(240x96x48)	2x(72x64x24)
Ratio	0.31	0.28

the turbulent boundary layers the time series of inflow velocities are generated from two separate LES calculations of flat-plate boundary layers with zero pressure gradient, using the method described by Lund et al. (1998). The inflow generation LES matches the local boundary layer properties, including the momentum thickness and Reynolds number,



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