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The new DF-SEM to generate inlet condition for embedded LES

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1 Introduction

Jarrin et al. (2009) developed the Synthetic Eddy Method (SEM) as a quasi-particle based method to generate synthetic turbulence conditions for embedded LES. The method esentially involves the superposition of a (large) number of random eddies, which are convected through a domain of rectangular cross-section. The resultant, time-dependent, flowfield from a cross-section of this SEM domain is extracted and imposed as inlet conditions for the LES. Using this approach Jarrin et al. (2009) found that LES of a channel flow at $Re_\tau = 395$ required a distance of around 10–12 channel half-widths to become fully-developed. Some further improvements were achieved by Pamiès et al. (2009), by specifically tuning the shape functions associated with the eddy representations for a channel flow. Although they did report a decrease in the required development length, the form adopted would appear to be rather specific to the application.

One of the perceived weaknesses of the above SEM methods is that the imposed inlet flowfield does not satisfy the divergence-free condition. As a consequence of this the LES tends to introduce significant pressure fluctuations close to the inlet (in order to adapt the velocity field to something that does satisfy continuity), and this adds to the required development length. In the present work, we therefore explore a method of extending the SEM approach in order to produce a suitable inlet velocity field that does satisfy continuity.

2 Numerical methods

In the SEM developed by Jarrin et al. (2006) and Jarrin et al. (2009), the fluctuating velocity field is generated by taking

$$\mathbf{u}'(\mathbf{x}) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N} a_{ij} \varepsilon_j^k f_\sigma(\mathbf{x} - \mathbf{x^k}) \tag{1}$$

where N is the number of eddies introduced into the SEM domain, $\mathbf{x}_k$ is the location of the centre of the kth eddy, $f_\sigma(\mathbf{x})$ is a suitable shape function, ε_j^k are random numbers and a_{ij} are coefficients. Although this formulation does allow the desired Reynolds stress field to be prescribed (via the a_{ij} coefficients), the velocity field will not, in general, also satisfy continuity.

The above formulation, applied to the vorticity and solved ($\nabla^2 \mathbf{u} = \nabla \cdot \mathbf{u} - \nabla \times \boldsymbol{\omega}$), leads, for a divergence free velocity field, to the following result:

$$\mathbf{u}'(\mathbf{x}) = \sqrt{\frac{1}{N}} \sum_{k=1}^{N} \mathbf{K}_\sigma\left(\frac{\mathbf{x} - \mathbf{x}^k}{\sigma}\right) \times \{R_L^G (\boldsymbol{\alpha}^k)^L\} \tag{2}$$

where the vector $\mathbf{K}_\sigma(\mathbf{y})$ is the Biot-Savart kernel, defined as $\mathbf{K}_\sigma(\mathbf{y}) = \frac{q_\sigma(|\mathbf{y}|)}{|\mathbf{y}|^3}\mathbf{y}$ with $q_\sigma(|\mathbf{y}|)$ a suitable shape function. R_L^G is a transformation matrix to rotate the desired Reynolds stress tensor to its principle axes (essentially, therefore, consisting of the three eignevectors of the Reynolds stress tensor). Finally, the vector $(\boldsymbol{\alpha}^k)^L$ is taken as having components $\alpha_i^k = \{C_i \varepsilon_i\}^k$, where the ε_i's are random numbers. If the coefficients C_i are taken as $C_i = \sqrt{\lambda_{max} - 2\lambda_i}$, where the λ's are the eigenvalues of the Reynolds stress tensor, then it can be shown that the form of equation (2) does return the desired Reynolds stress statistics. As a result of the form of equation (2), with certain conditions placed on the form of the shape function q_σ, the resulting velocity field cam also be shown to satisfy the divergence-free condition.

In the present work the shape function q_σ has been taken as

$$q_\sigma(y) = \sqrt{\frac{16 V_B}{15 \pi \sigma^3}} \left(\sin(\pi y)\right)^2 y \tag{3}$$

where V_B and σ are prescribed eddy velocity and lengthscales respectively.

3 Results

The method here described improves the performances of many other generative methods. Compared to some of the most well-known and used methods in a Channel Flow simulations ($Re_\tau = 395$, inlet data from Moser et al. (1999)) it showed a shorter influence to the calculated C_f (see Fig. 1).

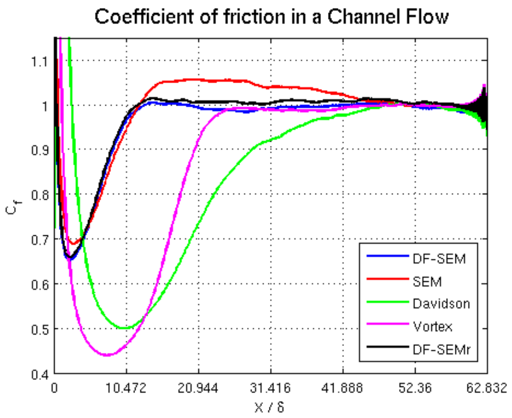

Figure 1: C_f performed in Channel Flows, $Re_\tau = 395$, using different inlet methods

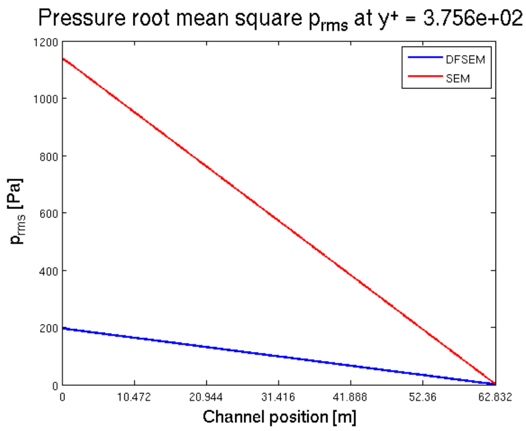

Figure 2: Pressure fluctuations

Regardless this positive result, a further problem rose: because of its stochastic nature, the method prescribes a constant average mass flow rate, but istanteneously it might vary whitin a range. This variation causes a gradient pressure fluctuations (Fig. 2). In fact, Navier-Stokes equations links the pressure gradient to the velocity time variations which is, in this case, imposed by the inlet method. A modification is then necessary: a mass flow rescalation is imposed at every time step in order to keep it constant. This modification slightly affects the divergence free condition of the method (the rescaling coefficient differs from 1 by less then 1% - Fig. 4) but highly decreases the pressure gradient fluctuations (Fig. 3).

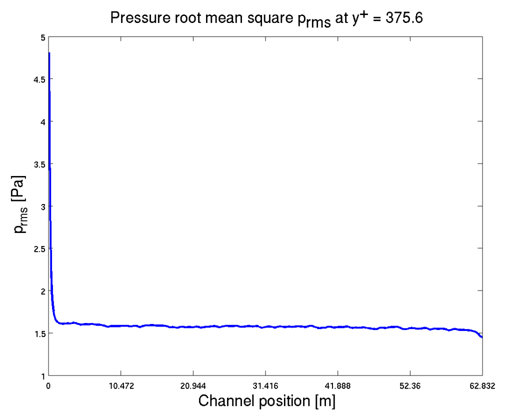

Figure 3: Pressure fluctuations after mass flow rescaling

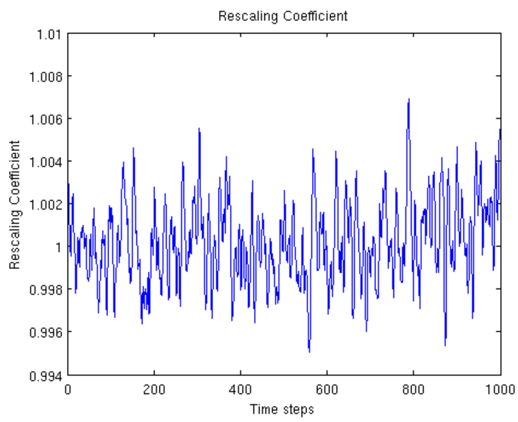

Figure 4: Rescaling coefficient used in the modified version of the DF-SEM

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