LES of channel flow using the explicit algebraic SGS stress model with the code_Saturne

Amin Rasam, Stefan Wallin, Geert Brethouwer & Arne V. Johansson

rasam@mech.kth.se

Linné FLOW Centre, KTH, Sweden

Introduction

Subgrid-scale (SGS) motions are not always isotropic, especially at coarse resolutions and in the vicinity of the walls. The eddy viscosity model (EVM), often used in large add simulation (LES), is not able to properly model the SGS stresses when the anisotropy in the SGS is significant. In Rasam *et. al.* [1], we showed that LES predictions using the EVM and a highly accurate pseudo-spectral code are very sensitive to the grid resolution and the predictions become inaccurate at coarse resolutions where the SGS anisotropy is considerable. The explicit algebraic SGS models (EASSM) [2, 4] are mixed nonlinear models that improve the predictions of the SGS stresses and scalar fluxes. Due to the better predictions of SGS fluxes by the EASSM, their predictions are less dependent on the grid resolution and are more accurate compared to other conventional SGS models. In this study, we perform LES of channel flow using the code_Saturne and the EASSM similar to our previous study [1] using a pseudo-spectral code.

The explicit algebraic subgrid stress model (EASSM)

The EASSM is obtained from the modeled transport equations of the SGS stress anisotropy and is adapted from the explicit algebraic model of Wallin & Johansson [3] for RANS. The EASSM consists of three terms

$$\tau_{ij} = K^{\text{SGS}}\left(\frac{2}{3}\delta_{ij} + \beta_1 \widetilde{S}^*_{ij} + \beta_4(\widetilde{S}^*_{ik}\widetilde{\Omega}^*_{kj} - \widetilde{\Omega}^*_{ik}\widetilde{S}^*_{kj})\right),$$

The second term on he right-hand side is an eddy viscosity term and the third term is a nonlinear term. $\widetilde{S}^*_{ij}$ and $\widetilde{\Omega}^*_{kj}$ are the normalized strain and rotation-rate tensors

$$\widetilde{S}^*_{ij} = \frac{\tau^*}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right), \quad \widetilde{\Omega}^*_{ij} = \frac{\tau^*}{2}\left(\frac{\partial \tilde{u}_i}{\partial x_j} - \frac{\partial \tilde{u}_j}{\partial x_i}\right).$$

β_1 and β_4 are coefficients that determine the relative contribution of the eddy viscosity and the nonlinear terms and are given by

$$\beta_4 = -\frac{33}{20}\frac{1}{\left[(9c_1/4)^2 + |\widetilde{\Omega}^*_{ij}|^2\right]}, \quad \beta_1 = \frac{9}{4}c_1\beta_4.$$

The SGS kinetic energy K^{SGS} is modeled as

$$K^{\text{SGS}} = c\,\Delta^2|\widetilde{S}_{ij}|^2,$$

where the model coefficient c is obtained using the Germano identity. The model coefficient c_1 is expressed in terms of the dynamic coefficient c

$$c_1 = c_1'\sqrt{c_3'\frac{c^{1.25}}{(2C_s)^{2.5}}}, \quad c_1' = 4.2, \quad c_3' = 2.4, \quad C = 1.6.$$

The SGS time scale τ^* is proportional to the inverse shear and is modeled as

$$\tau^* = c_3'\frac{1.5C^{1.5}\sqrt{c}}{2C_s}|\widetilde{S}_{ij}|^{-1}, \quad C_s = 0.1.$$

Channel flow simulations at $Re_\tau = 180$

LESs of channel flow are carried out using the code_Saturne with a constant bulk Reynolds number at two typical LES resolutions, see table below, and the EASSM, the EVM and with no SGS model. The schematic of the channel is shown in the figure below. The friction Reynolds number of the corresponding DNS is $Re_\tau = 180$.

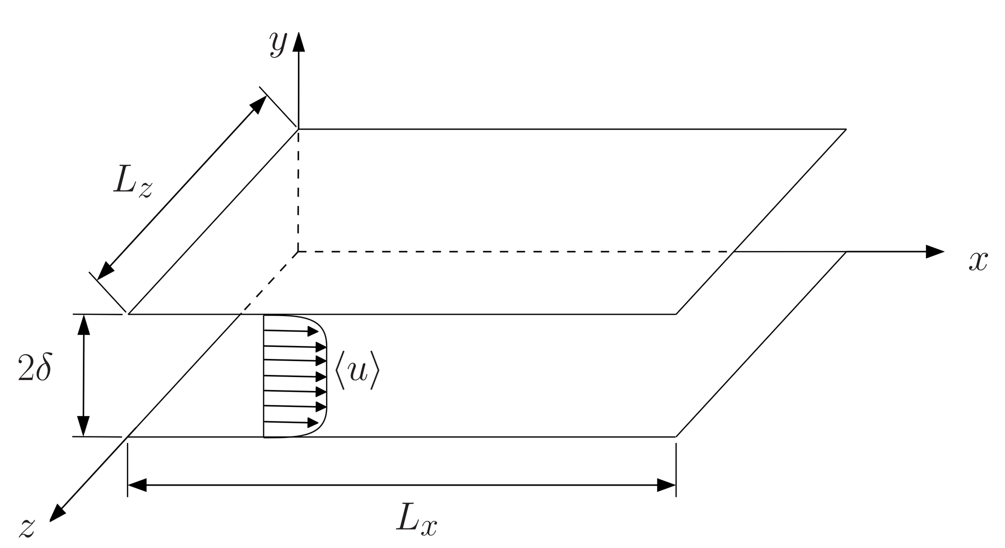

Fig.1:Schematic of the channel flow simulations

Table.1:Summary of the simulations

Case	SGS model	$n_x \times n_y \times n_z$	Δ_x^+	Δ_z^+	L_x	L_z	Re_τ
I	EASSM	$32 \times 33 \times 32$	67	33	$4\pi\delta$	$2\pi\delta$	170
II	EASSM	$48 \times 49 \times 48$	47	23	$4\pi\delta$	$2\pi\delta$	178
III	EVM	$32 \times 33 \times 32$	56	28	$4\pi\delta$	$2\pi\delta$	144
IV	EVM	$48 \times 49 \times 48$	47	23	$4\pi\delta$	$2\pi\delta$	153
V	–	$32 \times 33 \times 32$	62	31	$4\pi\delta$	$2\pi\delta$	158
VI	–	$48 \times 49 \times 48$	45	22	$4\pi\delta$	$2\pi\delta$	171

Mean velocity profiles and Reynolds stresses

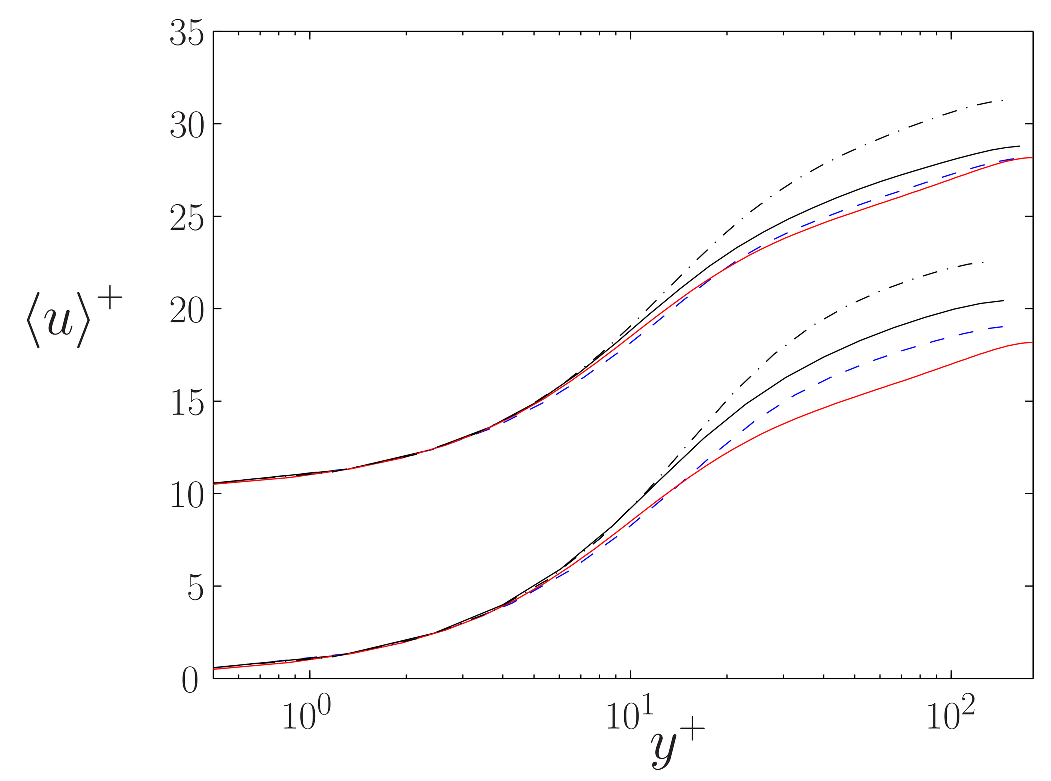

Fig.2: Mean velocity profiles in wall unit. Different resolutions are separated by a shift in the ordinate direction for clarity. Upper curves correspond to cases: II, IV and VI. Lower curves correspond to cases: I, III and V. DNS: red line; EASSM: dashed blue line; EVM: dash-dotted line; no SGS model: Solid black line

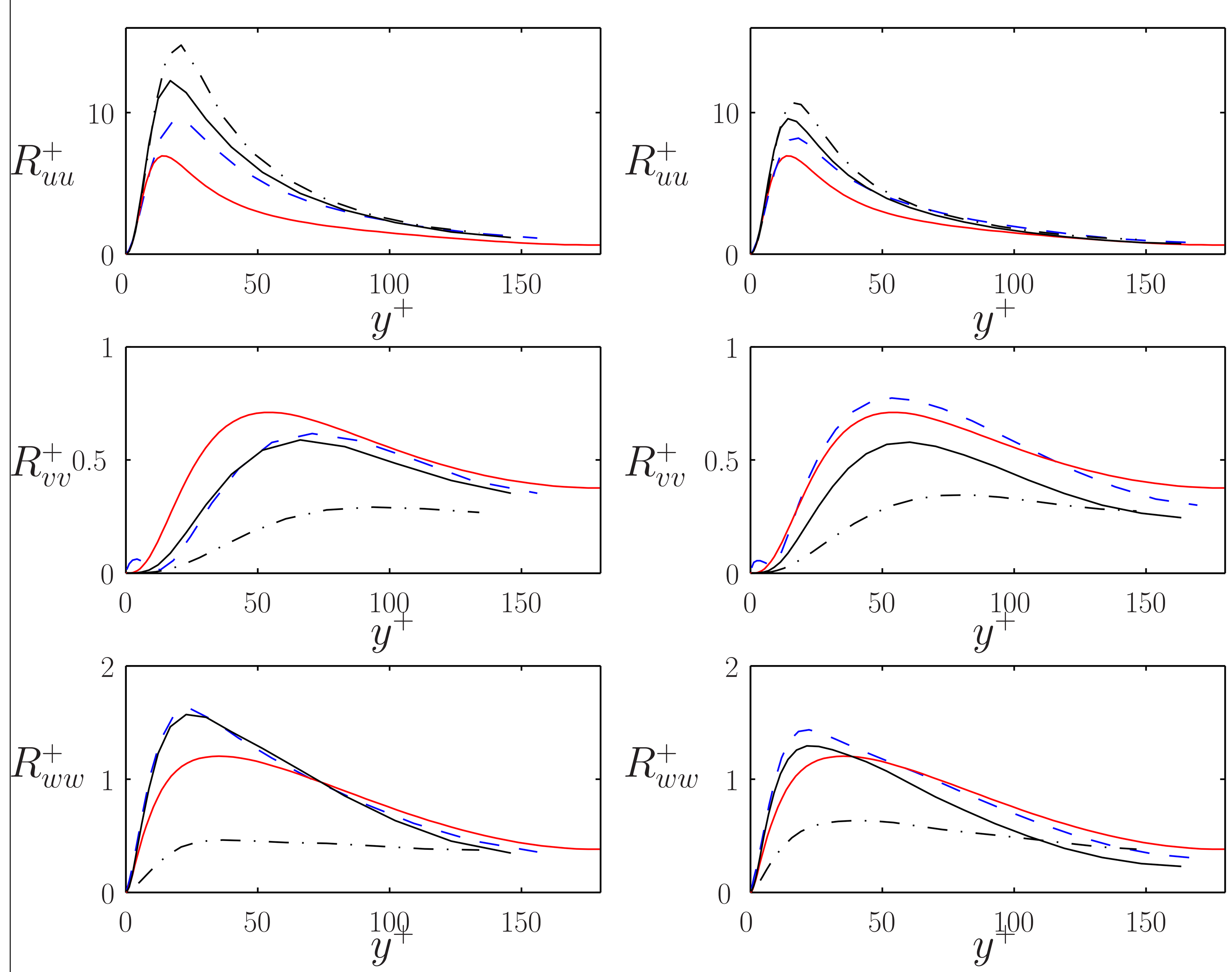

Fig.3: Reynolds stresses in wall unit. Left figures correspond to cases II, IV and VI. Right figures correspond to cases I, III and V. DNS: red line; EASSM: dashed blue line; EVM: dash-dotted line; no SGS model: Solid black line

Concluding remarks

- LESs of channel flow at $Re_\tau = 180$ were performed using the explicit algebraic SGS stress model and the results were compared to those of the dynamic eddy viscosity model, the no SGS model case and the DNS data.
- The LES predictions using no SGS model shows an under-prediction of the wall shear indicating that the code has numerical dissipation.
- The LES predictions using the dynamic eddy viscosity model shows a large under-prediction of the wall shear indicating that it provides for a large SGS dissipation.
- The EASSM considerably improves the LES predictions of the mean velocity, wall shear and Reynolds stresses.

References

[1] A. Rasam, G. Brethouwer, P. Schlatter, Q. Li and A. V. Johansson *Effects of modelling, resolution and anisotropy of subgrid-scales on large eddy simulations of channel flow 12(10)* 2011: J. Turbulence.

[2] L. Marstorp, G. Brethouwer, O. Grundestam and A. V. Johansson *Explicit algebraic subgrid stress models with application to rotating channel flow 639* 2009: J. Fluid Mech.

[3] S. Wallin and A. V. Johansson *An explicit algebraic Reynolds stress model for incompressible and compressible turbulent flows 403* 2000: J. Fluid Mech.

[4] A. Rasam, G. Brethouwer and A. V. Johansson *An explicit algebraic model for the subgrid-scale passive scalar flux 721* 2013: J. Fluid Mech.

This research was funded by the Swedish Research Council through grant number 621-2010-6965. Computer time provided by the Swedish National Infrastructure for Computing (SNIC) is gratefully acknowledged.