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Session:

Can anisotropy-resolving SGS models relax the resolution requirements in hybrid RANS-LES?

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Introduction

Anisotropy-resolving Reynolds stress turbulence modelling in a RANS context has been shown to be superior to standard eddy-viscosity models (EVM) in flows that are more complex than simple plane shear flows. Differential Reynolds stress models (DRSM) as well as their algebraic counterpart (EARSM) have been shown to be able to capture effects of rotation, curvature, swirl, secondary flows, non-equilibrium and separation onset somewhat better than EVMs.

Still massive separation and flows around blunt bodies cannot be well captured by RANS models mainly because of non-local effects, which is the primary motivation for hybrid RANS LES approaches. EARSM has been applied also in hybrid approaches for the attached RANS part, see e.g. Jaffrézic & Breuer [1], but the LES part is modelled using more standard EVM SGS modelling. It is commonly believed that the SGS turbulence is quite isotropic, which is true when the small scales are purely driven by an energy cascade in equilibrium. However, volume forces (rotation, stratification, …) and lack of an inertial range might enable anisotropies also on the SGS level motivating anisotropic SGS models.

A novel SGS model based on EARSM proposed by Marstorp et al. [2] has been shown to significantly relax the resolution requirement in plane channel and periodic hill flows, Rasam et al. [3, 4]. We will highlight these results and discuss the implications for hybrid RANS-LES modelling.

Results and discussion

The so-called EASSM SGS stress model is derived from a simplified EARSM, with only one non-linear term kept, which reads

$$\tau_{ij} = \frac{2}{3}\delta_{ij}K_{SGS} + \beta_1 K_{SGS}\tilde{S}^*_{ij} + \beta_4 K_{SGS}\left(\tilde{S}^*_{ik}\widetilde{\Omega}^*_{kj} - \widetilde{\Omega}^*_{ik}\tilde{S}^*_{kj}\right). \qquad (1)$$

The SGS kinetic energy, K_{SGS}, is derived from the filter scale and a dynamic procedure while the model coefficients $\beta_{1,4}$ are functions of $\tilde{S}^*_{ij}$ and $\widetilde{\Omega}^*_{ij}$, the normalised resolved strain- and rotation rate tensors.

The EASSM is applied in wall-resolved LES and compared with dynamic Smagorinsky (DSM). It shows significantly less resolution sensitivity; relaxing the total number of grid points by at least one order of magnitude. Fig 1 shows plane channel at Re_τ up to 5200. Resolution as coarse as $\Delta_x \times \Delta_z \approx 250 \times 100$ is sufficient for EASSM, while DSM fails. For the periodic hill in Fig 2, EASSM captures the essence of the flow separation also on the coarsest resolution where the separation completely vanishes by using DSM.

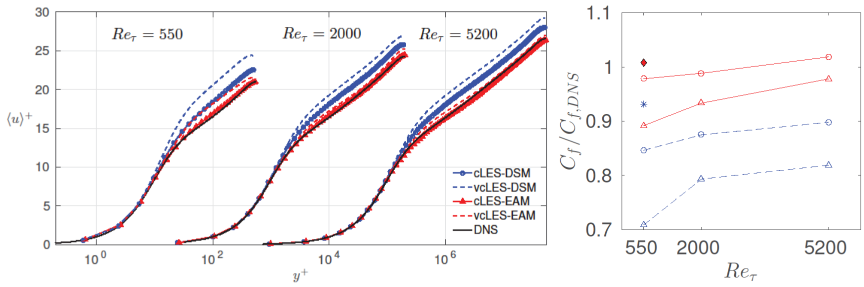

Fig. 1 Wall-resolved LES of plane channel flow for different resolutions ($\Delta_x \times \Delta_z \approx 150 \times 60$(c, ○), 250×100(vc, △)) at different Re using EASSM & DSM.

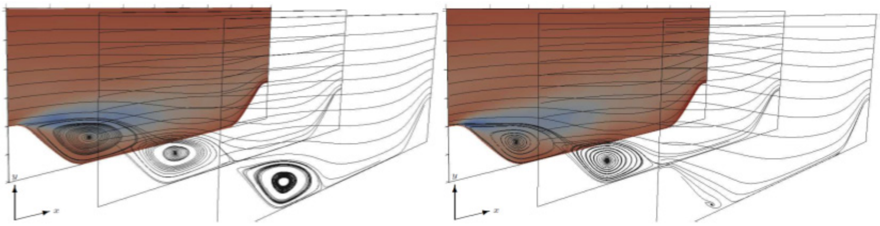

Fig. 2 Wall-resolved periodic hill flow for different resolution ($N_x \times N_z$=148×92, 128×80, 98×64 from left to right in each sub figure using EASSM (left) and DSM (right). Mean streamlines and colours by resolved $\overline{u'v'}$. Figure is taken from [5].

References

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[2] Marstorp, L. and Brethouwer, G. and Grundestam, O. and Johansson, A. V., J Fluid Mech. (2009) **639**, 403–432.
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