Importance of anisotropic subgrid-scale stress in large-eddy simulation of turbulent channel flows

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In turbulent shear flows, its anisotropic nature can decrease the validity of applying eddy-viscosity models in large-eddy simulations (LES). To see the effect of SGS stress $\tau_{ij}^{\mathrm{sgs}} (= \overline{u_i u_j} - \overline{u}_i \overline{u}_j)$ apart from energy transfer, we decompose τ_{ij}^{sgs} as follows[1]:

$$\tau_{ij}^{\mathrm{sgs}} = \frac{1}{3}\tau_{ij}^{\mathrm{sgs}} - 2\nu^{\mathrm{sgs}}\overline{s}_{ij} + \tau_{ij}^{\mathrm{ani}}, \quad \overline{s}_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right), \quad \nu^{\mathrm{sgs}} = -\frac{\tau_{ij}^{\mathrm{sgs}}\overline{s}_{ij}}{2\overline{s}_{\ell m}\overline{s}_{\ell m}}. \tag{1}$$

Here, $\bar{\cdot}$ represents the filter operation. Owing to this definition of ν^{sgs}, the anisotropic SGS stress τ_{ij}^{ani} does not contribute to the energy transfer; namely, $\tau_{ij}^{\mathrm{ani}}\overline{s}_{ij} = 0$.

We investigate the role of anisotropic stress τ_{ij}^{ani} in turbulent channel flows using direct numerical simulation. For details, refer to Inagaki and Kobayashi.[2] The cutoff wavelength scales are $(\lambda_x^{\mathrm{c}+}, \lambda_z^{\mathrm{c}+}) = (105, 52.4)$ (medium filter, MF) and $(\lambda_x^{\mathrm{c}+}, \lambda_z^{\mathrm{c}+}) = (209, 105)$ (coarse filter, CF). x and z are the streamwise and spanwise directions.

Figure 1(a) shows the contribution of several terms to the GS spanwise velocity fluctuation. For the CF case, the anisotropic redistribution is comparable to pressure redistribution and causes a positive SGS dissipation. As seen in Fig. 1(b), the positive anisotropic redistribution is dominant at the scale comparable to the coherent structure $\lambda_z^+ \approx 150$. This suggests that the anisotropy of SGS stress significantly contributes to the generation of coherent structures, e.g. streamwise vortices.

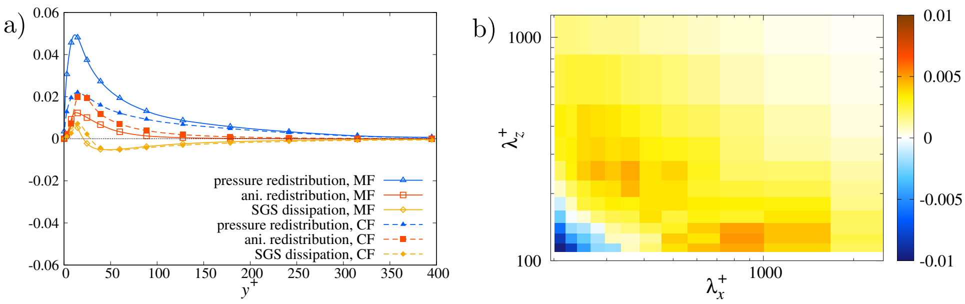

Figure 1: (a) Profiles of the spanwise component of pressure redistribution $2\langle \overline{p}'\overline{s}'_{zz}\rangle$, anisotropic redistribution $2\langle \tau_{z\ell}^{\mathrm{ani}}\partial\overline{u}'_z/\partial x_\ell\rangle$, and SGS dissipation $2\langle \tau_{z\ell}^{\mathrm{sgs}}\partial\overline{u}'_z/\partial x_\ell\rangle$. Here, $\overline{p}$ denotes the total pressure, $\langle\cdot\rangle$ represents the statistical average and $f' = f - \langle f\rangle$. (b) Two-dimensional spectra of the anisotropic redistribution for the CF case.

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[1]Abe, *Phys. Fluids* **31**, 105103 (2019).

[2]Inagaki and Kobayashi, *arXiv*:2301.12672.