A new turbulence model for large-eddy simulations of rotating flows

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Abstract

Rotating turbulent flows form a challenging test case for large-eddy simulations with commonly employed eddy viscosity models. We therefore propose a new subgrid-scale model that, in addition to an eddy viscosity term, contains a term that is nonlinear in the local velocity gradient through the rate-of-strain, S, and rate-of-rotation, Ω, tensors,

$$\tau^{\mathrm{mod}} - \frac{1}{3}\,\mathrm{tr}(\tau^{\mathrm{mod}})I = -2\nu_{\mathrm{e}}S + \mu_{\mathrm{e}}(S\Omega - \Omega S). \tag{1}$$

The nonlinear model term is perpendicular to the rate-of-strain tensor. As such, it does not directly cause production of turbulent kinetic energy, but it represents energy transport. We define the eddy viscosity, ν_{e}, and the transport coefficient, μ_{e}, as a function of the rate-of-strain and vortex stretching magnitudes. This latter quantity corrects the near-wall scaling and dissipation behavior of the Smagorinsky eddy viscosity model [1] and ensures that the nonlinear subgrid-scale model turns off in purely rotational and two-component flows [2].

Since the nonlinear term contains the rate-of-rotation tensor, Ω, the proposed subgrid-scale model is expected to have "a particular potential for [the simulation of] rotating flows" [3]. Figure 1 shows promising results of large-eddy simulations of a spanwise-rotating plane-channel flow obtained with the nonlinear subgrid-scale model of Eq. (1).

Keywords: turbulence modeling, large-eddy simulation, subgrid-scale modeling, rotating flows, Coriolis force

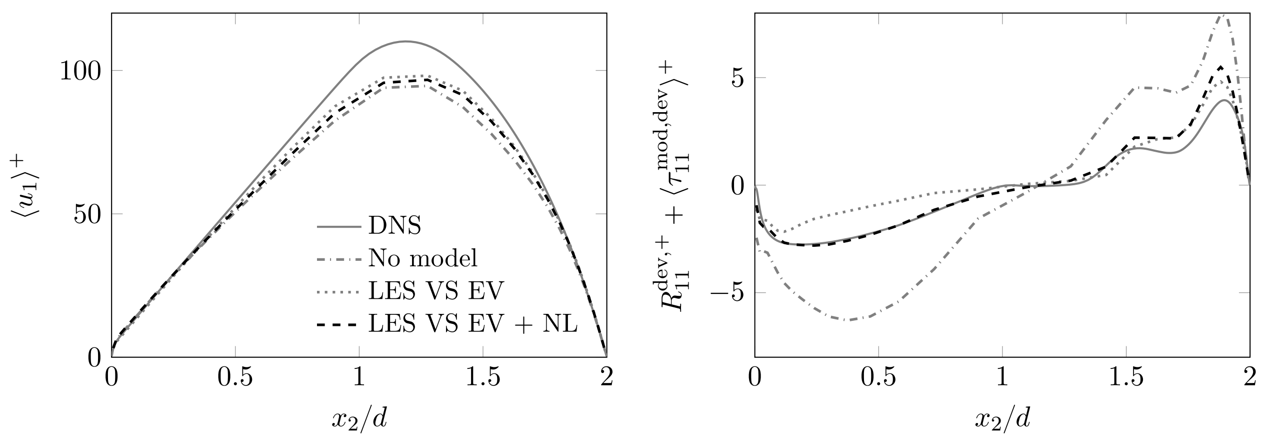

Figure 1: Mean velocity profile (left) and deviatoric streamwise Reynolds stress compensated by the model contribution (right), as obtained from large-eddy simulations of a spanwise-rotating plane-channel flow with $Re_\tau \approx 395$ and $Ro^+ = 100$ on a 32^3 grid. Results are shown for large-eddy simulations (LES) without a subgrid-scale model (dash-dotted gray line), with the vortex-stretching-based eddy viscosity (VS EV) model [2] (dotted gray line) and with the vortex-stretching-based nonlinear (VS EV + NL) model (dashed black line). Results from direct numerical simulations (DNS) on a $128 \times 256 \times 128$ grid are shown for reference (solid gray line).

References

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