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CONSTRAINED LARGE-EDDY SIMULATION OF WALL-BOUNDED FLOWS

Z. Xiao[1], Y. Shi[2], Z. Xia[3] and S. Chen[4]

[1] State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, P. R. China, z.xiao@pku.edu.cn
[2] State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, P. R. China, syp@mech.pku.edu.cn
[3] State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, P. R. China, xiazh1006@gmail.com
[4] State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, P. R. China, syc@pku.edu.cn

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Traditional large-eddy simulation (LES) of wall-bounded flows of engineering interest still remains a big challenge due to the intolerable computational cost. In such a context, a constrained large-eddy simulation (CLES) technique for simulation of wall-bounded flows is developed in both incompressible [1] and compressible [2] regimes. The fundamental idea of the CLES approach is to solve the coarse-grained Navier-Stokes equations in the entire domain with the subgrid-scale (SGS) models constructed in different forms within the near-wall and far-wall regions. In the far-wall region, traditional SGS models (e.g., Smagorinsky-Lilly model) is employed, and in the near-wall region, however, the mean SGS models need to satisfy prescribed constraint conditions for Reynolds quantities. In incompressible case, the total calculated Reynolds stress is balanced by an external Reynolds stress. In compressible case, the total calculated Reynolds heat flux is also constrained by given external Reynolds heat flux. The proposed CLES methods are tested and validated via simulations of several typical flows, including incompressible/compressible turbulent channel flows [1, 2], incompressible/compressible flow around a circular cylinder [1, 3], flow over a streamwise-periodic hills [4], flow past a commercial aircraft at large angle of attack [5], etc. The simulation results are well compared with those from experimental measurements and numerical simulation with various approaches.

For attached flows, the CLES method can eliminate the non-physical Log-Layer Mismatch phenomenon appearing in hybrid RANS/LES methods, and can predict the mean velocity and temperature profiles, friction force and other statistical quantities more accurately than traditional LES and hybrid RANS/LES methods. For detached flows, the CLES approach can calculate the skin friction force more precisely than traditional LES method, and is comparable to hybrid RAN/LES method in prediction of the aerodynamic statistics. For both cases, the CLES method can capture fruitful multiscale flow structures, which are largely lacking in the flow field given by hybrid RANS/LES method. Moreover, the CLES method proves to be much less sensitive to the grid resolution than traditional LES method. It is suggested that the proposed CLES method be a promising numerical simulation tool for wall-bounded flows in the sense of both scientific research and engineering application.

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