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LARGE-EDDY SIMULATION OF WALL-BOUNDED TURBULENT FLOWS WITH SEPARATIONS

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Mostly, the celebrated subgrid-scale (SGS) models for large-eddy simulation (LES) of turbulent flows perform less well than expected due to the lack of physically meaningful constraints. In this paper, a constrained large-eddy simulation (CLES) method for simulation of wall-bounded turbulent flows is introduced in order to open up a new way of modeling SGS effects.

For CLES of wall-bounded turbulent flows, the low-pass filtered Navier-Stokes equations are solved in the entire domain with the 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, whereas in the near-wall region, the mean SGS models are constrained by prescribed Reynolds quantities. In incompressible case, the total calculated Reynolds stress is balanced by an external Reynolds stress [1]. In compressible case, however, the total calculated Reynolds heat flux is also controlled by given external Reynolds heat flux in addition to the Reynolds stress [2].

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], supersonic turbulent boundary layer over a compression ramp [4], flow past a NACA0015 airfoil, etc. The simulation results are well compared with those from numerical simulations with various approaches and experimental measurements. The CLES method can eliminate the non-physical Log-layer mismatch phenomenon reported in hybrid RANS/LES methods (e.g., detached-eddy simulation, referred to as DES), 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 DES 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 methods. Moreover, the CLES method proves to be much less sensitive to the grid resolution than traditional LES method, and make pure LES of flows of engineering interest feasible with moderate grids. It is suggested that the proposed CLES methods should be a promising tool for simulation of turbulent wall flows with separations.

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