Seventh HRLM Symposium, 19-21 September 2018, Berlin, Germany

Session:

Reynolds-constrained Large-eddy Simulation: Sensitivity to Constraint and Subgrid-scale Models

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Introduction

Computational fluid dynamics (CFD) technique is playing increasingly important roles in the field of industrial engineering. Reynolds-averaged Navier-Stokes (RANS) simulation technique has been widely used in commercial software because of low requirement for computing grids, but its application to unsteady and separated flows remains questionable and unsatisfactory due to the lack of generality of turbulence models. Large-eddy simulation (LES) can predict three-dimensional (3D) and unsteady flow fields, however, it still requires fairly fine grids when used to solve the wall-bounded turbulent flows of engineering interest. Such a situation has considerably stimulated the development of hybrid RANS/LES methods, among which is the commonly employed detached-eddy simulations (DES) technique [1]. Yet with the inherent advantages, hybrid RANS/LES methods have problematic drawbacks. For example, DES encounters the well-known log-layer mismatch (LLM) defect in predicting a simple turbulent channel flow [2]. In order for the LES to be feasible to numerically predict wall-bounded turbulent flows, Chen *et al.* [3] proposed a Reynolds-constrained large-eddy simulation (RCLES) method, which opened up a new way of modelling subgrid-scale (SGS) effects for LES of wall-bounded turbulent flows.

Reynolds-constrained Subgrid-scale Modelling

In the RCLES Model for incompressible flows, the whole flow domain is simulated through solving the LES equations with the modelled mean SGS stress constrained by an external Reynolds stress balance condition in the near wall regions [3]. Such a Reynolds stress constraint, which is modelled based on the resolved velocity field without solving the RANS equations, can ensure mean velocity distribution near the wall, which can't be achieved in traditional LES if the mesh is not fine enough.

Jiang *et al.* [4] extended the RCLES method to wall-bounded compressible turbulent flows. In the compressible RCLES approach, a

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Reynolds heat flux balance condition is introduced to constrain the modelled mean SGS heat flux vector in addition to the Reynolds stress constraint. The performances of these RCLES approaches have been evaluated in simulations of turbulent channel flows, flows past a circular cylinder, supersonic flow over a compression ramp, etc. [3-6]. It's showed that RCLES methods can predict the mean velocity profile well without the LLM phenomena, and can calculate the skin friction more accurately compared with the DES method and traditional LES method using Smagorinsky models.

Sensitivity to Constraint and Base Models

Although the RCLES methods prove to have advantage over traditional LES approach in several situations, its sensitivity to the RANS and LES models remains unclear. The purpose of the present paper is to clarify this issue. Firstly, effects of the RANS models as constraint on results are discussed when base LES model is fixed. Secondly, insight is taken into influences of the base LES models when fixing the constraint model. Specifically, Baldwin-Lomax model, Spalart-Allmaras model, and Menter's SST $k-\omega$ model are selected as the constraint models, and Smagorinsky model and Wall-adapting local eddy-viscosity model for the base LES models. Simulations of compressible flows past a circular cylinder and a NACA0015 airfoil are carried out to demonstrate the dependence of RCLES method on the constraint and base SGS models.

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