Turbulence physics and modeling - overview

The turbulence physics and modeling group for this year's summer program encompassed a broad spectrum of relevant research topics. The topics include turbulence modeling in the Reynolds-averaged Navier-Stokes (RANS) and large-eddy simulation (LES) frameworks, utilization of a "manufactured" solution for mesh resolution estimation in LES of turbulent flame, investigation of the effect of "dynamic" roughness on wall-bounded flow, and exploration of the efficacy of steady state simulations for Rayleigh-Bénard convection at high Prandtl and Rayleigh numbers. Those topics are presented in the following five research papers.

In the first paper, Radhakrishnan, Pecnik, Iaccarino, and Kassinos implemented a version of algebraic structure-based turbulence model (ASBM) which incorporates one-point statistical information on the turbulence structure into an algebraic Reynolds-averaged closure, into CDP, an unstructured-grid flow solver. They showed encouraging results in the test cases such as flow over a backward-facing step and flow through an axisymmetric diffuser, of which predictions were difficult using linear eddy-viscosity models such as $k-\omega$ and v^2-f models. The ASBM coupled with unstructured-grid flow solver is expected to be especially useful in predictions of complex engineering flows.

In the second paper, Gorokhovski, Zamansky, and Vinkovic studied the non-filtered velocity field in channel flow computed by LES with a newly proposed stochastic model for the non-resolved (subgrid-scale) acceleration. Their stochastic subgrid-scale model is parameterized by the Reynolds number based on the friction velocity and the channel half-width and explicitly introduces the cross-channel correlation of subgrid velocity gradients. They showed that the model favorably represents intermittency effects in the near-wall region of a high-Reynolds number channel flow. Comparisons with DNS data also showed a favorable predictive capability of the model.

The third paper, by Lodato, Domingo, Vervisch, and Veynante, consists of two parts: the use of scalar variances for providing a LES mesh resolution criterion and the use of two-dimensional scalar gradients for estimating three-dimensional flame surface density. They introduced a "manufactured" solution of a turbulent premixed flame to discuss a LES mesh criterion which is based on the characteristic laminar flame and mean flame brush thickness. They showed that the manufactured solution well reproduces the scaling of scalar variance in terms of scalar gradient observed in the previous experiments, and therefore, scalar gradients from the manufactured solution can be utilized for comparing measured and LES variances. In the second part of the paper, they discussed the use of geometrical scalings and DNS results for a three-dimensional estimation of scalar gradients from two-dimensional measurements.

Wall roughness introducing additional length-scales to boundary layer flow has important implications for control of skin friction and associated improvements in vehicular efficiency. McKeon presented, in the fourth paper, a direct numerical simulation study to investigate the effect of time-dependent, "dynamic" roughness on wall-bounded flow. The effect of a roughness time-scale as well as a distribution of roughness length-scales is modeled by temporally-varying wall velocity components in a turbulent channel flow simulation. She found that significant roughness amplitudes are required in order to cause any change to the first and second moments beyond a local Stokes' layer dictated by the imposed wall velocity disturbances.

Finally, Hartlep and Ripoll reported three-dimensional simulations of a Rayleigh-Bénard convection phenomenon of interest to the glass industry. Their main objective was to assess the usefulness of steady state simulations for Rayleigh-Bénard convection at high Prandtl and Rayleigh numbers. Steady state simulations are found to well predict many aspects of the flow such as the small scale structure of spokes and convective plumes and the thickness of the boundary layers, while some time-dependent phenomena such as a large-scale plume network are not captured.

Donghyun You