# Constrained Large Eddy Simulation for Aerodynamics

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Using physical constraints on reduced set turbulent systems was first proposed by Kraichnan in the constrained decimation theory (Kraichnan 1985). In his approach, the effect of residual scales (subgrid scales) on the retained scales (large scales) is modeled by a stochastic forcing. To correctly calculate the mean energy flux or intermittency, the forcing term is constrained to satisfy certain constraint equations deduced from underlying physics, such as symmetry and conservation. In principle, the large eddy simulation method is equivalent to a physical space decimation method.

The idea of constrained variation has been recently extended in developing multiscale fluid turbulent models for constrained dynamic subgrid-scale stress model, Reynolds stress constrained large eddy simulation (RSC-LES) for wall-bounded turbulent flows with massive separation and heat flux constrained large eddy simulation. In the constrained dynamic subgrid-scale stress, we impose physical constraints in the dynamic procedure of calculating the SGS coefficients. The comparison between the large eddy simulation results in steady and decay isotropic turbulence using constrained and non-constrained SGS models and those from direct numerical simulation (DNS) will be presented.

For RSC-LES, our model is able to solve the traditional log-layer mismatch problem in RANS/LES hybrid approaches and can predict mean velocity, turbulent stress and skin friction coefficients more accurate than pure dynamic large eddy models and traditional detached eddy simulation using the same grid resolution for turbulent channel flow, flow past a circular cylinder, flow over periodic hills, Delta wing and other canonical flow systems. The application of the current model for aerodynamics, including simulating vortex-shock interaction in transonic flow with massive separation and whole airplane at different flow conditions, will be discussed. Our results demonstrate the capability of constrained variation in modeling complex turbulent systems.