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The Direct Deconvolutional Model in the Large-Eddy Simulation of Turbulence

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Abstract : The utilization of Large Eddy Simulation (LES) has been extensive in turbulence research. LES concentrates on resolving the significant grid-scale motions while representing smaller scales through subfilter-scale (SFS) models. The deconvolution model, among the available SFS models, has proven successful in LES of engineering and geophysical flows. Nevertheless, the thorough investigation of how sub-filter scale dynamics and filter anisotropy affect SFS modeling accuracy remains lacking. The outcomes of LES are significantly influenced by filter selection and grid anisotropy, factors that have not been adequately addressed in earlier studies. This study examines two crucial aspects of LES: Firstly, the accuracy of direct deconvolution models (DDM) is evaluated concerning sub-filter scale (SFS) dynamics across varying filter-to-grid ratios (FGR) in isotropic turbulence. Various invertible filters are employed, including Gaussian, Helmholtz I and II, Butterworth, Chebyshev I and II, Cauchy, Pao, and rapidly decaying filters. The importance of FGR becomes evident as it plays a critical role in controlling errors for precise SFS stress prediction. When FGR is set to 1, the DDM models struggle to faithfully reconstruct SFS stress due to inadequate resolution of SFS dynamics. Notably, prediction accuracy improves when FGR is set to 2, leading to accurate reconstruction of SFS stress, except for cases involving Helmholtz I and II filters. Remarkably high precision, nearly 100%, is achieved at an FGR of 4 for all DDM models. Furthermore, the study extends to filter anisotropy and its impact on SFS dynamics and LES accuracy. By utilizing the dynamic Smagorinsky model (DSM), dynamic mixed model (DMM), and direct deconvolution model (DDM) with anisotropic filters, aspect ratios (AR) ranging from 1 to 16 are examined in LES filters. The results emphasize the DDM’s proficiency in accurately predicting SFS stresses under highly anisotropic filtering conditions. Notably high correlation coefficients exceeding 90% are observed in the a priori study for the DDM’s reconstructed SFS stresses, surpassing those of the DSM and DMM models. However, these correlations tend to decrease as filter anisotropy increases. In the a posteriori analysis, the DDM model consistently outperforms the DSM and DMM models across various turbulence statistics, including velocity spectra, probability density functions related to vorticity, SFS energy flux, velocity increments, strainrate tensors, and SFS stress. It is evident that as filter anisotropy intensifies, the results of DSM and DMM deteriorate, while the DDM consistently delivers satisfactory outcomes across all filter-anisotropy scenarios. These findings underscore the potential of the DDM framework as a valuable tool for advancing the development of sophisticated SFS models for LES in turbulence research.

Keywords : deconvolution model, large eddy simulation, subfilter scale modeling, turbulence
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