Mechanical Engineering Doctoral Defense

Rational Boolean Stabilization of Subgrid Models for Large Eddy Simulations

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Abstract

This dissertation develops and demonstrates a new physics-based approach that provides computational stability of subgrid stress models in large eddy simulations while producing far smaller changes in the original subgrid stress and subgrid production fields than do current ad hoc stabilization methods. A pseudo-spectral code that is shown here to be almost entirely non-dissipative yet inherently stable without any subgrid model is used to conduct simulations with stable and unstable subgrid stress models. Results show that initial instability, subsequent exponential growth, and eventual machine overflow occur via a highly localized dynamical process that results from interactions among terms in the kinetic energy and enstrophy transport equations. This process begins first at one material point and then occurs at increasingly more material points, with local exponential growth rates of kinetic energy and enstrophy being the same for all points, until machine overflow eventually occurs at the material point where the process began first. A Lagrangian backtracking scheme is developed and applied to this material point, allowing backward-in-time tracking of all terms in the kinetic energy and enstrophy transport equations. This gives insights into the dynamics that produce this local instability and its subsequent exponential growth, with the initial instability shown to result from interactions between the subgrid production and subgrid redistribution terms. Elementary backscatter limiting based on locally reducing individual subgrid stress components that contribute to local kinetic energy backscatter is shown to stabilize any stress model but still produces substantial changes in the stress and production fields. The rational Boolean stabilization method instead uses the local subgrid production and subgrid redistribution rates to determine where and how individual subgrid stress components must be rescaled to provide local backscatter limiting and/or forward scatter amplification. This stabilizes all subgrid stress models while producing only small changes in the subgrid stress and production fields. Rational Boolean stabilization is computationally fast and can be generalized to stabilize models for other subgrid terms in large eddy simulations while producing only small changes in their resulting fields. This solves a key problem that has previously limited the accuracy of large eddy simulations.

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