

# Variational and Multiscale Methods in Turbulence with Particular Emphasis on Large Eddy Simulation

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**Abstract:** Calculating turbulent flows requires solution of the Navier-Stokes equations at high Reynolds numbers. This is referred to as Direct Numerical Simulation (DNS). However, it is currently not feasible to perform DNS for all but the simplest turbulent flows due to prohibitive computational requirements. Even if current rates of increase of computational power continue, it is unlikely DNS will become an everyday engineering tool in this century! The problem stems from the fact that turbulence is characterized by a very broad spectrum of spatial and temporal scales and although engineering interest is focused on the behavior of the larger scales their dynamics is influenced by the presence of small scales due to nonlinear interactions.

Large Eddy Simulation (LES) is a procedure in which only larger scales are resolved numerically, and effects of smaller scales are modeled. This reduces computational requirements significantly and currently enables solution of many physically interesting flows. Recently, LES has become an important engineering tool. Even with LES, turbulent calculations still require enormous computational resources but there is hope that through continued improvements in computer performance and modeling concepts LES will emerge as the standard technology for computing flows of engineering interest.

The devil is in the details: There is still no general agreement as to best modeling procedures within LES, and even the proper theoretical framework of LES is debated. The presentation begins with a brief overview of traditional LES concepts and identifies points of concern. Elementary modeling ideas are reviewed and examined from numerical analysis and "spectral eddy viscosity" points of view. The variational multiscale formulation of the Navier-Stokes equations is proposed. It has features which obviate some of the criticisms of the classical LES formulation and provides a framework with potential for improved modeling. Computations employing the simplest instantiations of the ideas are presented for homogeneous isotropic flows and channel flows, and in all cases very good results are obtained. Particular accuracy is noted for non-equilibrium flows.