Chapter 14
DNS and LES of Turbulence-Combustion Interactions

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Abstract One of the most successful applications of direct numerical simulation (DNS) has been in the study of turbulent combustion. This is due to the ability of DNS to resolve the full range of time and length scales in which turbulence and chemical reactions interact with each other. One prominent example is the turbulent diffusion flame, in which turbulent mixing determines the main characters of combustion while chemical reactions strongly influence turbulence. The present chapter focuses on turbulence-combustion interactions in variable-density flows, in which turbulent fluctuations in pressure, density and other variables play important roles. The phenomena of combustion-generated turbulence, decreased Reynolds stress anisotropy, counter-gradient diffusion, and combustion-generated buoyancy can all be attributed to the coupling between turbulence and chemical heat release through density and pressure fluctuations. In contrast, the application of large eddy simulation (LES) in turbulent combustion has been slow and controversial, but carries a huge potential. The subgrid-scale modeling difficulties are not only related to the treatment of the highly non-linear chemical source term, but also connected to the handling of extra subgrid terms in the energy and species transport equations, as compared with the case of non-reacting flow. The existence of counter-gradient diffusion, and the significance of viscous diffusion and dissipation in combusting flow present particular challenges. Despite all the difficulties, LES has been successfully used in simulating turbulent reacting flows under comparable conditions as found in experiments, subject to certain limitations. One example is the simulation of buoyant reacting plumes in which flow transition, intermittency and fully-developed turbulence co-exist.

14.1 Introduction

The interaction between turbulence and combustion is a topic of great interest and complexity that defies an analytic solution or even an basic understanding in most cases. This is especially true in the case of turbulent non-premixed flames (also called diffusion flames) in which turbulence and chemical reactions are strongly coupled. The difficulties associated with the problem are manifold: (a) Turbulence has a wide range of time and length scales, each of which has a different effect on mixing and consequently combustion; (b) The chemical reaction rate is a highly nonlinear function of flow variables such as temperature and density; (c) Combustion involves a large