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Applications of Turbulent Combustion Modeling

By Daniel C. Haworth
Department of Mechanical & Nuclear Engineering
The Pennsylvania State University
University Park, PA 16802-2321 USA
dch12@psu.edu

Multidimensional modeling (computational fluid dynamics - CFD) is playing an increasingly important role in advanced combustion-system development. Improvements in performance are demanded across all applications, while at the same time it is necessary to reduce fuel consumption and pollutant emissions and to accommodate alternative fuels. The coverage is necessarily incomplete. Topics have been selected based on the author's experience and interests, and to complement the coverage in the other lectures in this series. A brief overview of turbulent combustion modeling is provided first, with an emphasis on the aspects that are highlighted in subsequent sections. Three subjects then are discussed in more detail: transported probability density function methods, radiation heat transfer modeling, and soot modeling. Application "case studies" for laboratory flames and piston engines are presented where Reynolds-averaged or spatially filtered modeling approaches have been been used, and examples of direct numerical studies for canonical configurations and laboratory flames are discussed. The final section includes observations on the progress of turbulent combustion modeling over the past 10-20 years, current trends in modeling, and near-term predictions for future applications of turbulent combustion modeling.

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1. Introduction

Turbulent combustion remains an important and timely subject in engineering science. Many of the most urgent energy efficiency, energy security, global climate change, and pollutant emission issues worldwide are related to the conversion of chemical energy to sensible energy (heat) via a combustion process in a turbulent flow environment. Combustion devices of practical interest include stationary and automotive reciprocating-piston internal-combustion (IC) engines, stationary and aircraft gas-turbine combustors, and industrial burners. The combustion process in such devices usually is characterized by complex turbulence-chemistry interactions that span multiple combustion regimes: premixed flame propagation, mixing-controlled burning, and chemical-kinetics-controlled processes may occur simultaneously within a single device. A wide range of flow speeds (Mach numbers) may be relevant. Multiple-phase flows (liquid fuel sprays, solid particles), heterogeneous combustion (walls/catalysts), and radiation heat transfer (high-pressure and/or large-scale systems, sooting flames) often are important. This complex turbulent aero-thermo-chemistry typically takes place in tortuous three-dimensional geometric con-