Preface

This volume contains the 2013 annual research briefs of the students, postdoctoral fellows, research associates, visiting and senior research fellows of the Center for Turbulence Research (CTR). There are 25 reports contained in this volume, reflecting the wide breadth of topics that conform the research activities at CTR. Support for these activities is equally diverse, including programs sponsored by the Department of Energy (PSAAP, SciDAC), NASA, the Department of Defense—through the Defense Advanced Research Projects Agency (DARPA), the Air Force Office of Scientific Research (AFOSR), the Office of Naval Research (ONR), and the Naval Air Systems Command (NAVAIR)—several industrial partners, and international research agencies.

This year marked the conclusion of the Predictive Science Academic Alliance Program (PSAAP), a five-year endeavor sponsored by the Department of Energy through the National Nuclear Security Administration (NNSA). At Stanford, PSAAP focused on the quantification of margins and uncertainties for the design and safe operation of scramjet engines utilized in hypersonic flight propulsion. Throughout the program, CTR played a decisive role in the development and application of simulation capabilities and uncertainty quantification methodologies, which were both fundamental components of the program. Nearly one third of the reports contained in this volume received PSAAP support.

The first group of reports is concerned with the application of high-fidelity simulations to study complex multi-physics flows. We start with simulations of scramjet and rocket propulsion systems that integrate combustion models with wall models and real-fluid effects, respectively. New developments in two-phase flow modeling follow in two reports: first, simulation of turbulent bubbly flows with a newly developed, fully-conservative volume-of-fluid based methodology is considered; second, two novel approaches—one based on real-gas tabulation and the other on a Lagrangian stochastic model of the rate of vapor production—are applied to simulations of cavitation relevant to diesel engines. The final two reports in this first group explore the coupling of electromagnetic fields and turbulence from opposite extremes in scale: the first focuses on radiative magnetohydrodynamics simulations of the local solar dynamo, whereas the second considers inductively-coupled plasma lenses and their optical performance under unsteady effects, complementing simulations with theoretical developments that act as a liaison with the next group of reports.

Physics-based modeling is the underlying theme in the second group of reports, two of which are concerned with spray flame structure: the first introduces a new mixture fraction definition and modeling assumptions to ensure monotonicity and enable the use of a passive scalar to describe the structure of the spray flame. The second formulates laminar combustion models for spray ignition in both non-premixed and partially-premixed spray systems. The third report sheds light into the backscatter of turbulent kinetic energy from the subgrid scales in large-eddy simulations (LES) of turbulent chemically-reacting compressible flows. The final report in this group switches our attention from fossil-fuel energy conversion to renewable energies, by assessing the suitability of point-forcing models in LES of vertical axis wind turbines (VAWTs) to investigate how farm-scale effects can increase the generated power density.

The third group of reports focuses on hydrodynamic and thermoacoustic instabilities, and wall-bounded turbulence. The first report demonstrates the transition of electroosmotic instabilities into chaotic flow by direct numerical simulations (DNS), complemented with a linear stability analysis. The thermoacoustic instabilities that drive the power generation in traveling-wave thermoacoustic Stirling heat engines are the object of study of the second report in this group. The third report addresses open questions and challenges in the study of acoustic combustion instabilities through simulations, highlighting the need for thermoacoustic solvers to complement LES solvers. The fourth report in this group investigates H- and K-type transitions of a laminar boundary layer to turbulence by applying the dynamic mode decomposition (DMD) technique to DNS databases. A non-equilibrium wall model for LES is developed in the next report, implementing and partially validating the model within a fully unstructured-mesh solver. A study of the dynamics of superhydrophobic, textured walls through DNS is reported next, emphasizing the effect of the texture on pressure fluctuations, followed by a simulation of thermal boundary layers and heat losses in the pulsatile flow occurring inside the cylinders of internal combustion engines.

Synergistic efforts at CTR between theory, simulations and experiments are highlighted in the next three reports. The first is an experimental investigation of the flutter of filaments in planar flows using PIV, designed with an eye on the validation of future simulations involving flow/structure interactions. The second presents high-fidelity simulations of an inclined jet in a crossflow for film-cooling applications, targeting an MRI-based experiment conducted in parallel at Stanford. In collaboration with experimentalists at the High Temperature Gas Dynamics Laboratory at Stanford, the third report investigates, from an uncertainty quantification vantage point, the influence of uncontrolled residual impurities present in shock-tubes on the determination of hydrogen ignition times.

The final group of reports in this volume is devoted to novel developments of numerical methods and to the application of computational methodologies to perform and analyze large-scale simulations. New developments in numerical methods include improvements of high-order filter schemes for simulations of shock-turbulence interaction, the formulation of hybrid adjoints for RANS simulations and the extension of Discontinuous Galerkin methods for multi-phase flows. Post-processing and exploration of large datasets generated during the execution of massively parallel multi-physics simulations require new approaches that can bridge the Big Data and High Performance Computing paradigms. This is particularly relevant in a year in which CTR performed parallel simulations with its in-house multi-physics flow solvers at unprecedented computing scales, by simultaneously utilizing the nearly two million processors available on the latest generation of IBM Blue Gene/Q supercomputers deployed at Lawrence Livermore National Laboratory.

The reports presented in this volume are further testament to the Center's commitment to tackle increasingly complex multi-physics problems by integrating theoretical developments, physics-based modeling, advanced numerical methods and computational techniques, making use of some of the most powerful supercomputers in the world.

It is a great pleasure to thank Rika Bosmans for her help in the production of this volume, and for her day to day management of CTR. The CTR roster for 2013 is provided in the Appendix. This volume is available on the World Wide Web at the CTR website (`http://ctr.stanford.edu`).

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