Preface

The eighteenth biennial Summer Program of the Center for Turbulence Research (CTR) was held from July 17 to August 12, 2022. CTR hosted 71 participants from 15 countries, including 20 U.S. institutions. 40 CTR staff members, including graduate students, postdoctoral fellows and faculty, worked alongside the participants. 35 project teams were selected on the basis of the quality of their research proposals and their synergy with the current scientific interests of CTR. The role of CTR continues to be that of providing a forum for the fundamental study of multiphysics turbulent flows for engineering analysis. As a result of additional synergistic collaborations between participants, 41 projects were carried out during four-week program.

This proceedings volume contains 41 reports that are divided into six groups: Modeling Turbulence and Transition Using Data-Driven Approaches, Data-Driven Methods, Multiphase and Particle-Laden Flows, Combustion, Analysis of Turbulent Boundary Layers and High-Fidelity Simulations and Applications. Preceding each group of papers is a technical overview that summarizes the main accomplishments of each group.

While data analysis has always been at the foundation of the CTR Summer Programs, a major theme of this year's program was data-driven modeling. The group on Modeling Turbulence and Transition Using Data-Driven Approaches focused on developing predictive models for wall-bounded flows. These projects used supervised and reinforcement learning, proper orthogonal decomposition and the macroscopic forcing method. These models combined classical physics-based modeling principles with data-driven closure techniques.

The Data-Driven Methods group focused on developing novel techniques drawing on principles from optimization, resolvent analysis and deep learning. The group had two main research thrusts: (i) acceleration of numerical simulations with data-based closures, and (ii) developing reduced-order descriptions of turbulence for making predictions and deriving physical insight.

Research activities in the group on Multiphase and Particle-Laden Flows focused on the analysis and modeling of dispersed particle-laden turbulence and two-phase turbulent flows. In the area of particle-laden turbulence, this group studied numerical methods for coupling the momentum of the fluid and dispersed phases, the effect of subgrid-scale modeling on particle transport and innovative methods for computing particle statistics. In the area of two-phase flows, the focus was on the modeling of phase change in interfacial flows, microconfined turbulence in high-pressure transcritical conditions and current-driven instabilities in plasmas.

A primary focus of the Combustion group was investigating how the unique properties of hydrogen combustion require novel computational methods and models. Other activities included an investigation of iron-powder combustion and the high-fidelity simulations of high-temperature gas-turbine combustors and rotating detonation engines.

The Analysis of Turbulent Boundary Layers group conducted several investigations of canonical, rotating, deforming and high-speed boundary layers. In addition to analyzing turbulence structure and dynamics, new analysis techniques were developed for accounting for compressibility and pressure-gradient effects.

Finally, development of methodology and validation of large-eddy simulation technique to complex flows was the focus of the High-Fidelity Simulations and Applications group.

The applications included drag reduction, trailing edge noise, transition process in high-speed boundary layers and performance of a helicopter rotor in hover.

As in previous years, four weekly tutorials were given during the Summer Program. The topics discussed in the tutorials this year were "Machine learning for turbulence modeling" by Adrián Lozano-Durán (MIT), "Resolvant analysis of turbulent flows" by Beverley McKeon (Caltech), "The transition to hydrogen: simulations of future engines and safety scenarios" by Thierry Poinsot (CERFACS-CNRS), and "Interface-resolved simulations of multiphase turbulent flows: achievements and new challenges" by Luca Brandt (KTH).

The participants of the 2022 Summer Program presented their accomplishments on August 12. This final event was attended by several colleagues from industry, academia and government.

The 2022 Summer Program was sponsored by the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Department of Energy (DoE), and the Office of Naval Research (ONR). The joint commitment of four different federal agencies to support the program underscores the importance of understanding and modeling multiphysics turbulent flows for engineering analysis. The wide discretionary mandate they afforded to CTR for selection of the technical projects featured in these volumes is much appreciated.

We are grateful to Vi Nguyen, Susan Dorman and Pamela Nelson Foster for their assistance and efficient organization of the 2022 CTR Summer Program, to Catrin Hunter for her assistance preparing this volume and to Steve Jones for his guidance to the external participants who utilized the CTR Yellowstone cluster for their simulations.

This volume is available online at the CTR website:
`http://ctr.stanford.edu/`

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