Preface

The nineteenth biennial Summer Program of the Center for Turbulence Research (CTR) was held from June 23 to July 19, 2024. CTR hosted a record number of 103 participants from 15 countries representing 60 institutions (29 international and 31 U.S.). A total of 41 CTR staff members, including graduate students, postdoctoral fellows, and faculty, worked alongside the participants on 49 research projects during the four-week program. The participants presented their accomplishments on July 19. The final event was attended by several colleagues from academia, industry, and government.

The role of CTR continues to be that of providing a forum for the fundamental study of multiphysics turbulent flows that play a key role in prediction and control of complex engineering and environmental problems. The 49 reports in this volume cover a broad range of topics divided into six groups: Fundamentals, Data-Driven Methods, High-Speed Flows, Multiphase Flows, Predictive Methods, and Geophysical Fluid Dynamics. Preceding each group of reports is a technical overview, prepared by the group coordinators, that summarizes the main accomplishments of each group.

The Fundamentals group studied the structure and modeling of transitional and turbulent boundary layers, including effects of pressure gradient and surface roughness as well as flow instability and transition modeling in complex external flows. The projects tackled several problems of current technical interest, including the effect of Crow instability on radiative properties of contrails and development of a novel RANS model for separated transitional flows over airfoils.

As in the 2022 Summer Program the burgeoning field of data science had a large presence in the program with 11 projects. The Data-Driven Methods group incorporated a variety of techniques including resolvent analysis, adjoint methods, Bayesian inference, data assimilation, compressive techniques for rapid flow analysis, autoencoders, and machine learning to gain physical insights, facilitate control of flow instabilities or shape optimization, and improve turbulence models. Some of the projects used experimental data in their analysis, such as incorporating experimental data in a machine learning algorithm for prediction of aircraft ice accretion and assimilation of flow-MRI data of mean and turbulent kinetic energy into turbulence models.

The High-Speed Flows and Propulsion group investigated the effect of turbulent fluctuations and nonequilibrium chemistry in hypersonic flows, identified acoustically radiating sound sources in supersonic and hypersonic flows, and studied energy transfer mechanisms in supersonic combustion. The projects tackled a variety of practical problems, including for instance, nonequilibrium chemistry effects on communication blackout characterization around atmospheric entering vehicles and characterization and impact of wind tunnel noise on transition mechanisms on hypersonic vehicles.

The seven reports in the Multiphase Flows group analyzed numerical methods for capturing phase interfaces, including aggressive adaptive mesh refinement strategies, and development of robust and nonlinearly stable schemes for phase field equations. Parallel efforts were devoted to modeling multiphysics effects such as phase change, cavitation, hyperelastic material response, and melting and devolatilization of plastics. High-fidelity simulations were used to gain insight into energy transfer mechanisms at the phase change interface, where resolved surface tension energy was shown to correlate with subgrid-scale turbulence production.

The Predictive Methods group was concerned with models and methods for predicting multiphysics flows at engineering complexity and assessment of whether current models work at scale. To that end, further understanding was gained of the effect of mixed precision arithmetic in computational fluid dynamics and gained insight into trainability barriers in machine-learning-based subgrid-scale models. Applications included investigations of the operational stability of a detonation engine, heat flux from fire engulfed objects in crosswind, aircraft icing aerodynamics, and unsteady multiscale interactions within a multistage compressor.

Turbulence in geophysical settings is a recent focus area at CTR in close collaboration with the faculty at the Stanford Doerr School of Sustainability. Research activities in the Geophysical Fluid Dynamics group included studies of turbulence energetics and mixing in oceans, sediment transport, and atmospheric transport and dispersion.

An important feature of the CTR Summer Program over the years are the weekly tutorials. The topics discussed in the four tutorials this year were: “How to address the separation of temporal and spatial scales in modeling multiphase flow systems,” by Miad Yazdani of the RTX Research Center; “Pressing issues in geophysical turbulence and modeling,” by Oliver Fringer and Leif Thomas of Stanford; “Unravelling surface roughness effects on wall turbulence,” by Bharathram Ganapathisubramani of the University of Southampton; and “Scientific machine learning and real-time digital twins,” by Luca Magri of Imperial College London.

The 2024 Summer Program was sponsored by the United States Office of Naval Research, with important contributions from the National Science Foundation and NASA. The wide discretionary mandate they afforded to CTR for the selection of technical projects is much appreciated. We are grateful to Vi Nguyen and Pamela Nelson Foster for their assistance and efficient organization of the 2024 CTR Summer Program. Many thanks are due to Carlos Gonzalez for his assistance preparing this volume, which is available online at: `http://ctr.stanford.edu/`.

Parviz Moin & Beverley McKeon