



Preface

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Turbulent mixing and beyond: non-equilibrium processes from atomistic to astrophysical scales

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Turbulent mixing is a source of paradigm problems in physics, engineering and mathematics. Beyond this important interdisciplinary role, it has immense consequences for a broad range of applications in astrophysics, geophysics, climate and large-scale energy systems. In two volumes, we summarize and provide a perspective on the topic through some 20 articles focusing on turbulent mixing and beyond. The volumes are grouped, somewhat loosely, into those associated with fundamental aspects of turbulence and those specific to Rayleigh–Taylor turbulent mixing.

We developed the programme 'Turbulent mixing and beyond' (TMB) to bring together researchers from different areas of science, engineering and mathematics, and to focus their attention on the fundamental problem of turbulent mixing [1,2].

Turbulent mixing is a non-equilibrium turbulent process that occurs in a broad variety of natural phenomena and technological applications, ranging from astrophysical to atomistic scales and from high- to low- energy-density regimes (see [2] and references therein). Examples include inertial confinement fusion, light–matter interaction, strong shock waves, explosions, supernovae and accretion discs, convection in stellar and planetary interiors, premixed and non-premixed combustion, hypersonic and supersonic flows—both wall-bounded and boundary-free—as well as the atmosphere and the ocean [3–10]. A good grasp on

turbulent mixing is crucial for the cutting-edge technology in laser micro-machining and free-space optical telecommunications, and for traditional industrial applications in the areas of aeronautics [3,6,11,12]. In some of these applications (e.g. combustion processes), turbulent mixing should be enhanced, whereas in some others (inertial confinement fusion) it should be mitigated. However, in all circumstances, we have to understand the fundamentals of turbulent mixing, be able to gather high-quality data and derive knowledge from these data, and, ultimately, achieve a better control of these complex processes.

The TMB programme spans fluid dynamics, plasmas, high-energy-density physics, astrophysics, material science, combustion, Earth sciences, nonlinear physics, applied mathematics, probability, statistics, data processing, computations, optics and communications, and other areas [1]. Non-equilibrium turbulent processes are present everywhere, and are exceedingly difficult to study in their direct manifestation. At macroscopic scales, their properties depart substantially from those of canonical Kolmogorov turbulence [13–16]. At atomistic and meso-scales, their non-equilibrium dynamics differ from a standard scenario given by the Gibbs ensemble [17,18]. Their theoretical description is intellectually challenging, as it has to account for the multi-scale, nonlinear, non-local and statistically unsteady character of the dynamics [5,7,19–24]. Their numerical modelling effectively pushes the boundaries of computations to the exascale level and demands significant improvement of numerical methods in order to capture shocks, track interfaces and accurately account for the dissipation processes, non-equilibrium and singularities [18,25]. On the experimental front, these processes are a challenge to implement and systematically study in a well-controlled laboratory environment [26]. They are sensitive to details and are transient, and their dynamics impose unusually tight requirements on the accuracy and resolution of flow measurements, as well as on data acquisition rates [3,12,27,28]. Furthermore, because of their statistical unsteadiness, systematic interpretation of these processes from experimental data alone is neither easy nor straightforward [12,26].

Despite these challenges, the tremendous success that has been achieved in the past 20 years in large-scale numerical simulations (e.g. large-scale numerical modelling of a supernova explosion and nuclear burning [18,25]), in laboratory experiments (especially those in high-power laser systems [6,8]), in technology development (including possibilities for improvements in precision, dynamic range, reproducibility, motion-control accuracy, and data acquisition rate [12]), in theoretical analysis (in particular, new approaches for handling complex multi-scale, non-local and statistically unsteady transport [7,9,10,23,24]) renders unparalleled opportunities to explore properties of turbulent mixing and probe the matter at the extremes. This success as well as the striking similarity in behaviour of non-equilibrium turbulent processes in vastly different physical regimes make this moment right for integrating our knowledge of the subject and for further enriching its development.

Thus, with the support of the international scientific community and international funding agencies and institutions, we founded the TMB programme. We saw its goals in the development of new ideas for understanding the fundamentals of turbulent mixing, in applications of novel approaches for description of a broad range of phenomena where these processes occur, and in the potential impact on technology development [1].

In 2010, the *Philosophical Transactions of the Royal Society A* published the first volume based on the material presented at TMB-2007 [2]. Now, in two companion volumes, we summarize and provide a perspective through some 20 papers focusing on the theme of the programme. The first volume represents the broad variety of themes of the programme, and is concerned with fundamental aspects of turbulence, mixing and non-equilibrium dynamics. The second volume is focused on one of the key problems of the programme—the Rayleigh–Taylor instabilities and mixing.

We hope that the programme will expose the world of turbulent mixing phenomena and that an inquisitive mind will be fascinated by the opportunity to capture the universality of non-equilibrium dynamics and to elaborate new concepts, whose lucidity and simplicity can cut through the complexity of the problem.

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