Turbulence and Transition Physics — overview

A number of fundamental aspects with regard to turbulence and transition dynamics remain major outstanding questions in physics. These problems range from transitional boundary layers and post-transitional wall-bounded turbulence, to the sound generated from shear layers and wakes. All of them are of practical interest for increasing the aerodynamic performance of a wide range of engineering systems.

The specific topics addressed by this group can be subdivided into three themes: i) transition physics and modeling, which deals with the study of the early turbulent structures in both boundary layers and transitional wakes; ii) analysis and control of wall-bounded turbulence, which focuses on the dynamics of the flow structures in turbulent boundary layers and channel flows; and iii) noise generation and propagation, which addresses the problem of aeroacoustics in shear layers and airfoil wakes. Remarkably, the projects in this group encompass these topics in engineering scenarios where a number of multi-physics phenomena make the description even more challenging. These range from high-speed compressibility effects, flow-structure interactions in boundary layers, and wall-bounded heated flows of supercritical fluids. A brief description of the research activities undertaken by the group members on each theme is given below.

i) Transition physics and modeling. The subgrid-scale (SGS) predictive modeling of transition to turbulence in boundary layers is an unsolved problem for which there is yet no clear alternative to costly direct numerical simulations. It is expected that SGS modeling approaches of transitional flows should heavily rely on knowledge of the statistical structure of turbulence upon transition. This is precisely tackled in Wu's work (Skarda *et al.*), which provides a statistical analysis of transitional turbulence spots, including insights into their dynamics, frequency and geometry. At high speeds, the process of transition becomes more complicated, in that the energy transfer involved in transition can be heavily influenced by compressibility effects, including the aerothermal coupling with the wall heat transfer, as suggested by the simulations and linear stability analyses reported in Shadloo *et al.*'s work. In the aerodynamic design of hypersonic aircrafts, additional considerations must be given to the effects of wall deformations on the dynamics of transitional boundary layers. These are addressed in Bodony's project in a detailed linear stability analysis that provides increased knowledge of the coupling between the wall compliant motion and the early development and propagation of flow disturbances upon transition. In almost all practical applications, the boundary layer gives rise to a wake downstream of the aft body that largely contributes to the drag. The project led by Rigas focuses on the prediction of the loss of symmetry in three-dimensional transitional wakes from blunt-edged bodies.

ii) Analysis and control of wall-bounded turbulence. A requirement for an eventual theory of wall-bounded turbulence, which still remains elusive to us all, is the detailed understanding of the dynamics of the characteristic structures emerging from the interaction with the wall. The work of Yang *et al.* proposes a new diagnostics tool for identifying wall-bounded vortical structures based on a formulation for vortex-surface evolution. Non-isothermal effects in strongly heated channel flows of supersonic gases and supercritical fluids occupy the attention of the project led by Pecnik (Patel *et al.*), which proposes an effective scaling based on the local Reynolds number to parametrize the velocity profiles in the presence of large gradients of viscosity and density. The passive control of turbulence in the intake of hypersonic engines is tackled by Schreyer *et al.* in a study that combines experiments and large-eddy simulations of the effects of mounting arrays of sub-boundary-layer microamp vortex generators to alter the interaction of a hypersonic flow over a compression ramp. In all these wall-bounded turbulence problems, it is not straightforward to identify the precise causes of observed effects. In this regard, the work reported by Liang attempts to employ tools of causality analysis to identify the causal relation between streamwise rolls and streaks in turbulent channel flows.

iii) Noise generation and propagation. The shear layers that emerge from jets or wakes in airfoils are sources of noise. A pacing item in aeroacoustics research is the fundamental characterization and predictive modeling of the mechanisms of noise generation and propagation in complex turbulent flows. In the work led by Moreau (Sanjose *et al.*), direct numerical simulations and linear stability analyses are performed to study the noise radiation from transitional boundary layers and wakes in airfoils; a snapshot of the simulations performed in this project is featured in the cover picture of this volume. Lastly, the report of Afsar *et al.* makes use of large-eddy numerical simulation databases of supersonic heated jets to propose a reduced-order model for noise propagation.

As in previous years, the topics addressed by this group have received considerable attention in planning the research activities for the Summer Program. Specifically, the ten projects in the Turbulence and Transition Physics group were tackled by twenty participants coming from thirteen institutions of seven different countries. The group greatly benefited from twelve CTR staff members who contributed to the projects. The collaborative atmosphere and the collegial environment of the group were remarkable. Many collaborations established with members of other groups during the Summer Program enabled rapid progress in each project and laid the ground for future joint work among the participants.

On a personal note, I would like to thank Sanjiva Lele for the many discussions that emerged from his timely questions during the group meetings.

Javier Urzay