Stability analysis of turbulent boundary layer flows with adverse pressure gradient

Jean-Philippe Laval[1,2], Matthieu Marquillie[1,2], & Uwe Ehrenstein[3]

[1] CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France
[2] Univ Lille Nord de France, F-59000 Lille, France
[3] Aix Marseille Univ, IRPHE UMR 6594, CNRS, F-13384 Marseille 13, France
jean-philippe.laval@univ-lille1.fr

The turbulent boundary layer flow subjugated to adverse pressure gradient coming from curvature are of crucial importance for many applications including aerodynamics of airfoils, ground vehicles or turbine blades. Significant progress are needed in understanding the near wall turbulence in order to improve the theoretical and numerical models. The available numerical models usually fail as they are based on scaling of wall turbulence which are no more valid with pressure gradient. Therefore, a careful analysis of turbulent structures generation are the only opportunity to make progress in designing accurate statistical models for turbulence. The Direct Numerical Simulation (DNS) of the Navier Stokes equations is an efficient tool to study the complete time and 3D space behaviors of the full range of turbulent structures. DNS was already used to identify and to study the cycle of generation of turbulent structures in turbulent boundary layer without pressure gradient. A large experimental and numerical database of turbulent boundary layer were generated through the European project WALLTURB in order to extract physical understanding of these flows.

In flows with sufficiently high pressure gradients, a strong peak of turbulent kinetic energy have been observed and not yet fully explained. Through the analysis of a DNS database of a converging-diverging channel, the origine of intense coherent structures was identified and linked to the linear instability of the flow. The instability of the normal profile of the mean streamwise velocity is not satisfactory to fully explain the generation of the coherent vortices observed in the DNS. However, the linear stability analysis of the spanwise varying average streak (which is the most energetic long structure in the vicinity of the wall) superimposed to the normal profile is able to predict both the streamwise location and the shape of the coherent structures. These structures quickly evolve according to the non-linearity of the Navier Stokes equations to elongated vortical structures which are able to redistribute the turbulent kinetic energy in the three directions.

The drawback of the DNS is the limitation in term of Reynolds number. On the other hand, the progress on experimental tools for flow characterization are significant as quantitative analyses in three dimensions are now possible. However, the accuracy and the spatial resolution of methods such as tomographic Particles Image Velocimetry are not yet satisfactory for careful investigations of near wall turbulent structures.