Direct Numerical Simulation (DNS) of Turbulent Boundary Layer with Adverse Pressure Gradient

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Context and objective:

Although aerodynamics has made tremendous progress in the last century, it still lacks both reliable turbulence models and the physical understanding to develop better ones. In fact, turbulence remains one of the great challenges of engineering and natural sciences; and especially for flow near the solid surfaces which is unavoidably met with any aircraft. The adverse pressure gradient which occur whenever a flow decelerates along a wall is particularly problematic. It is an essential part of any aerodynamic flow field and decisive for the drag experienced. It is hence a key to breakthrough designs of lower drag. However, even today, existing turbulence models are deficient in this situation and often require extensive case dependent tuning. Improving turbulence models require a better knowledge on the specificity of flow physics under adverse pressure gradient which is accessible only from well designes experiments and realistic numerical simulations.

The objectives identified for external aerodynamics also apply to the design of engine compressors and turbines, the aim being lighter engines, with higher efficiency at a larger range of design conditions. The efficiency of the recent aircraft (Airbus 380, Boeing 777) is of the order of 45%, which is the results of significant progress over the last 20 years. To go further, the designers need to turn to higher loads on the blades of the compressor and the turbine, but with the guaranty to safely avoid flow separation in the whole flight envelop. This is only possible with reliable prediction of the APG boundary layers on the suction side of the blades. Improving the efficiency can partly be achieved by reducing the number of blades at each stage of the engine, thus by making the blade profiles more "aggressive", potentially leading to separation. Due to the difficulty of performing accurate measurements in the interior of engines, numerical prediction by statistical turbulence models is one of the main design tool used in industry. Any improvement on the prediction of the effect of presssure gradient would lead to a significant reduction of the design cycle and the fuel consumption.

Laboratory

Laboratoire de Mécanique de Lille (LML, UMR CNRS 8107, http://www.univ-lille1.fr/lml/) is a joint laboratory between Université de Lille *1*, Ecole Centrale de Lille, Ecole Nationale des Arts et Métiers, and CNRS. About 70 researchers and University teachers work in the fields of Civil Engineering, Solid Mechanics and Fluid Dynamics.

The team hosting the PhD thesis [1] is involved in fondamental an applied research on turbulence (both experimental and numerical), and optical measurement techniques. It is participating to European projects and networks on all these aspects. A specific numerical code for Direct Numerical Simulations (DNS) and Large Eddy Simulations (LES) of such flows with Adverse Pressure Gradient (APG) using a mapping of coordinate has been developed by the team [2]. This code with high order spatial discretization is well suited for this type of flows with curvatures. The numerical code has been modified to handle massively parallelized simulations in order to provide an efficient tool for the simulations of flows at Reynolds number representative of realistic configurations. This type of flows have many research interest in different domains such as Aeronautics, Automotive industry or Energy production (wind turbines).

Recently, the team has performed several experiments and large Direct Numerical Simulations (DNS) of Adverse Pressure Gradient flows at significant Reynolds numbers [3,4]. The database is part of a larger database generated within the European project WALLTURB on zero pressure gradient and adverse pressure gradient turbulent wall bounded flows. The objective of the team is to pursue the study of such flows in order to generalize the behaviour observed in our configuration to all adverse pressure gradient flows at large Reynolds numbers. This study will be conducted using both new experiments and new numerical simulations.

Subject

The aim of the current PhD is to perform a DNS of turbulent boundary layer flow on a curved wall at higher Reynolds number and in several adverse pressure condition taking into account all the experience of the previous DNS. Then, the physic of turbulence as well as the characterization of coherent structures will be analysed in detail in order to validate or to propose new scaling and numerical models of turbulence in similar configurations. The work will be done in closed collaboration with a team in charge of experiments one the same type of flows.

Candidate

The candidate will have an aptitude for computational work, the ability to work in a team and, importantly, an enthusiasm for the subject area. Candidates must have a M.Sc degree and a strong background in fluid mechanic (ideally turbulence) and computer science is required.

[1] http://lml.univ-lille1.fr/lml/equipe/er2/
[2] M. Marquillie J.-P. Laval and R. Dolganov, Direct Numerical Simulation of separated channel flows with a smooth profile, J. Turbulence (9) 1-23 (2008)
[3] M. Marquillie, U. Ehrenstein and J.-P. Laval, Instability of streaks in wall turbulence with adverse pressure gradient, Journal of Fluid Mechanics, 681, 205-240 (2011)
[4] http://www.deisa.eu/science/deci/projects2006-2007/DNS-BUMP