DIRECT NUMERICAL SIMULATION OF THE HEAT TRANSFER OF AN IMPINGING JET

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Abstract Direct Numerical Simulation of a circular jet impinging a flat plate is carried out in order to study the heat transfer distribution on the wall. Instantaneous and averaged velocity and temperature fields are analysed while focusing on the link between the spatio-temporal evolution of the vortical structures and the spatial distribution of the Nusselt number.

INTRODUCTION

Impinging jets are widely used in industrial applications as efficient tools to optimize the heat transfer between the flow and the impinged wall. While they have been consequently the subject of extensive experimental and numerical research [1, 2, 3, 4], the relation between the vortical structures of the flow and the heat transfer on the wall remains unclear. In particular, experimental studies conducted at the Institute PPRIME (*e.g.* [6, 5]) have highlighted the appearence of a secondary peak in the radial evolution of the mean Nusselt number. Identifying the physical mechanisms responsible of this phenomenon is an extremely difficult task, because measurement techniques cannot provide the evolution of the instantaneous quantities of interest in all space simultaneously. Thanks to recent progress in massively parallel computing, it is now possible to simulate the spatio-temporal evolution of a realistic turbulent impinging jet using Direct Numerical Simulation (DNS). In the present study, a DNS of a circular confined jet impinging a flat plate is performed in a flow regime corresponding to the reference experiments. The nozzle to plate distance is set to $H/D = 2$ with a Reynolds number of $Re = U_b D/\nu = 10000$. Instantaneous velocity and temperature fields coupled with turbulent statistics are then analysed while focusing on the region of the secondary maximum of the Nusselt number.

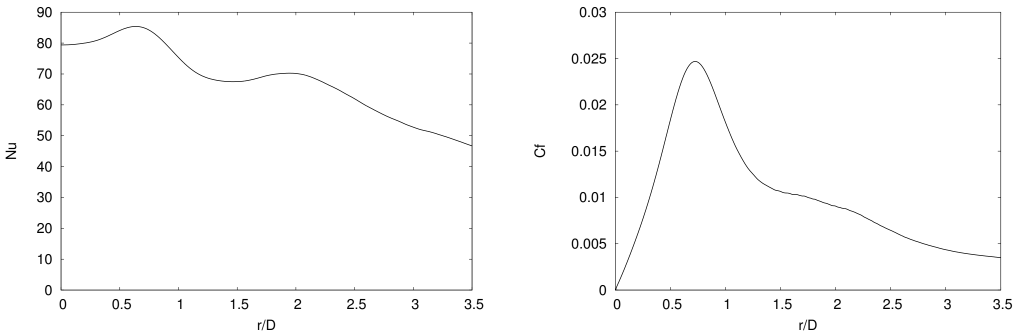
NUMERICAL METHODS

To solve the incompressible Navier-Stokes equations, a numerical code called **Incompact3d** is used. This code is based on sixth-order centered compact schemes for the spatial discretization and a third-order Adams-Bashforth scheme coupled with an implicit second-order Crank-Nicolson scheme for the time advancement. The pressure mesh is staggered from the velocity mesh to avoid spurious pressure oscillations. With the help of the modified wave number concept, the divergence free condition is ensured up to machine accuracy. More details about the present code and its validation, especially the original treatment of the pressure in the spectral space, can be found in the papers of Laizet *et al.* [9, 10]. Moreover the massively parallel version of the code (with MPI implementation and based on pencil domain decomposition strategy) is used in this numerical study [11].
At the inlet of the jet, the streamwise component of the mean velocity is prescribed using a power law profile and the temperature is kept constant. At the outlet boundaries, a convective outflow condition is used for the temperature and a Dirichlet condition associated with a buffer zone is used for the velocity. The use of a buffer condition seems to be the best approach to damp the parasite interactions between the outflow and jet inflow [12]. Standard no-slip boundary conditions are applied at the top and bottom plates for the velocity. Concerning the temperature, its ambient value is prescribed on the confinement plate and a constant heat flux is applied on the impingement plate in order to mimic the reference experiments. In this study, the mesh is regular in the transverse directions and stretched in the axial direction of the jet in order to concentrate the grid points near the impingement wall. The DNS resolution is obtained using $1201 \times 401 \times 1201$ mesh nodes.

RESULTS

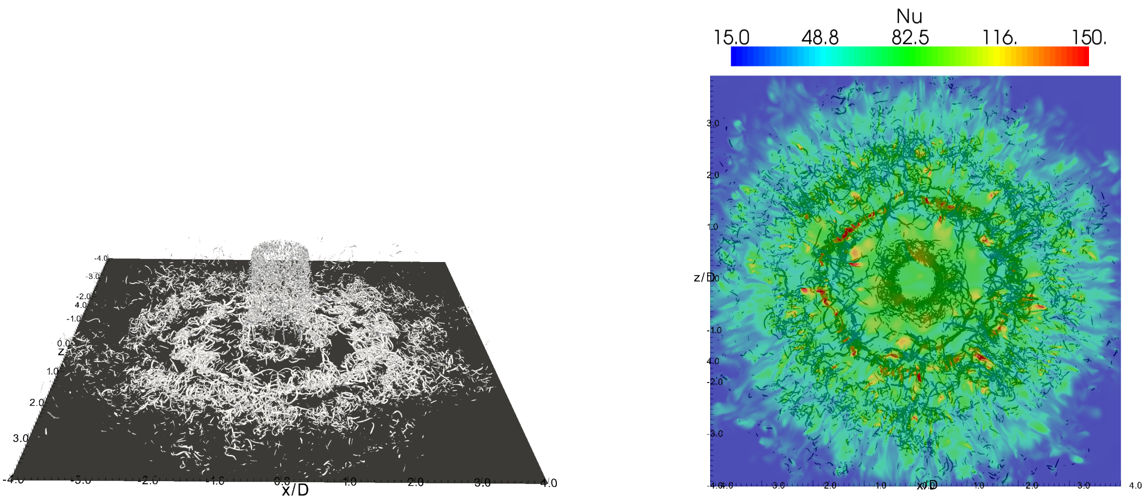
The distributions of the mean Nusselt number and skin friction coefficient along the impinged plate are given in figure 1. The statistical convergence of the data is not fully reached here and a complete statistical analysis will be presented in the final paper for the velocity and temperature fields. However, the primary and secondary peaks are already detected in the Nusselt number profile (see figure 1(a)) with a first maximum at $r/D \approx 0.7$ corresponding to the impact of the structures issuing from the jet shear layer and a secondary maximum localised at $r/D \approx 2$. The first peak is recovered on the skin friction coefficient at the same location (see figure 1(b)) and a change in slope is also visible in the vicinity of the secondary peak position. These peaks are interpreted as a signature of dynamical events that drive locally the heat transfer. An example of instantaneous fields is given in figure 2. The *Q-criterion* iso-surface plotted in figure 2(a) highlights a complex vortex dynamics involving large scale toroidal structures visible from $r/D \approx 1.5$ and various small scale turbulent structures. The instantaneous Nusselt number distribution on the wall is plotted in figure 2(b) with the

Q-criterion iso-surface shown in rear view by transparency. The regions of heat transfer enhancement are found to be strongly correlated with the location of the large scale toroidal structures. The instantaneous Nusselt number distribution seems also be connected with the small-scale dynamics as shown by the very localised and intense heat transfers associated with the presence of fine-scale vortices elongated in the radial direction. The detailed information offered by the present DNS should enable us to better identify the role of large- and small-scale vortex structures on the instantaneous and mean heat transfer. Particularly, their respective contribution on the secondary maximum of the mean Nusselt number should be a very challenging behaviour to capture numerically. An additional feature suggested by the preliminary analysis of instantaneous fields is the highly intermittent character of the instantaneous Nusselt number distribution. In the final paper, connections will be established between the intermittency of the near-wall dynamics and the local heat transfer.



(a) (b)

Figure 1. Mean radial distributions of (a) the Nusselt number and (b) the skin friction coefficient on the impingement wall.



(a) (b)

Figure 2. Examples of instantaneous fields : (a) Perspective view of an iso-surface of *Q-criterion* ($Q = 150$) in the 3D computational domain, (b) Rear view of the Nusselt number distribution on the impingement wall. The iso-surface of *Q-criterion* is visible through the wall by transparency.

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