DIRECT NUMERICAL SIMULATION OF HEAT TRANSFER OF ROUND SUBSONIC IMPINGING JETS AT HIGH REYNOLDS NUMBER

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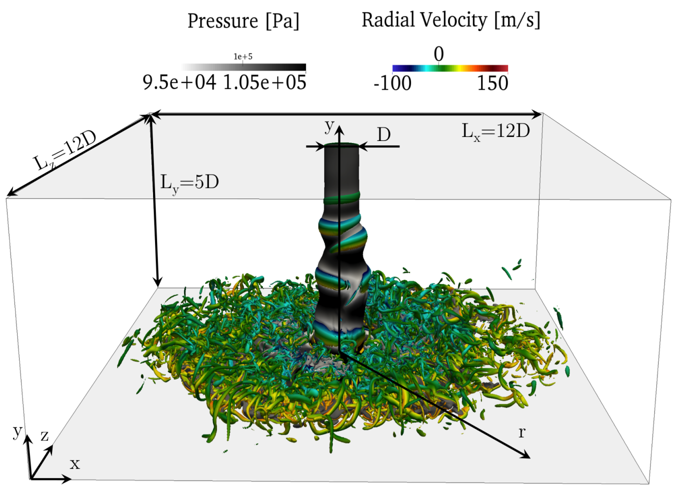
Abstract Impinging jets provide an effective cooling method for various applications such as the cooling of aircraft turbine blades. The latest generation of high performance computers allows us to investigate those at practically relevant Reynolds numbers Re by means of direct numerical simulations. In order to analyse the heat transfer of a confined round impinging jet, two direct numerical simulations are performed at $Re = 3300$ and $Re = 8000$ using a grid of $512 \times 512 \times 512$ respectively $1024 \times 1024 \times 1024$ points. Each configuration is fully turbulent. The first one features two annular regions with local maxima of heat transfer at the impinging plate. These effects are related to high wall-normal turbulent heat fluxes caused by vortical structures of the turbulent flow field. The second simultion is ongoing. Its results will also be presented on the conference.

INTRODUCTION

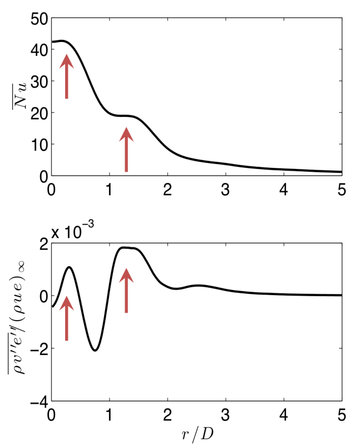
Heat transfer due to forced convection of a jet impinging on a flat plate has been studied for decades. General information including schematic illustrations of the flow fields as well as distributions of local Nusselt numbers for different geometrical configurations and Reynolds numbers Re can be found in several reviews based on experimental and numerical results. A three-dimensional direct numerical simulation is the most recent approach to investigate the physics of the impinging jet and offers additional information such as statistical quantities describing turbulence.

NUMERICAL SETUP

The governing Navier-Stokes equations are formulated in a characteristic pressure-velocity-entropy-formulation, as described by Sesterhenn [4] and solved directly numerically. The spatial discretisation uses 6th order compact central schemes of Lele [3] for the diffusive terms and 5th order compact upwind finite differences of Adams et al. [1] for the convective terms. To advance in time, a 4th order Runge-Kutta scheme is applied. The computational domain has the dimension $12 \times 5 \times 12$ diameters and is shown in Figure 1a. The two walls are isothermal. All other boundaries are non-reflecting.



(a) Snapshot of the computational domain with iso-surfaces at $Ma = 0.2$ coloured with pressure and at $Q = 105 m^2 s^{-4}$ coloured with radial velocity. $Re = 8000$



(b) Mean radial distributions of the local Nusselt number (top) and the turbulent heat flux (bottom). $Re = 3300$

Figure 1: Computational domain and heat transfer

RESULTS

The heat transfer at the impinging plate is strongly related to the vortical structures of the turbulent flow field. In the shear layer of the jet (primary) ring vortices develop and grow until they collide with the lower wall. The high pressure at the stagnation point turns the flow direction away from the jet axis and parallel to the wall. The primary vortices follow that direction and a secondary counter-rotating ring vortex develops. These structures enhance the local heat transfer in an annular shape, directly followed by a likewise annular area of poor heat transfer. Travelling downstream the vortices become unstable and break down into smaller structures that rise. As a consequence the two rings at the wall of very high and low heat transfer vanish and the cycle restarts. The presently described phenomena agree with the experimental results of Buchlin [2].

The periodical appearance and disappearance of the vortex pairs lead to a high averaged turbulent heat flux at $r/D = 0.3$ and $r/D = 1..1.4$, as indicated in Figure 1b. This is exactly where the averaged Nusselt number reaches its local maxima. Given these results, the aim for future work is to enhance the vortices and thereby the wall normal turbulent heat flux concluding in a more efficient cooling of the impinging plate. The results will be complemented with an analysis of the budget equations for the Reynolds stresses and the turbulent heat flux.

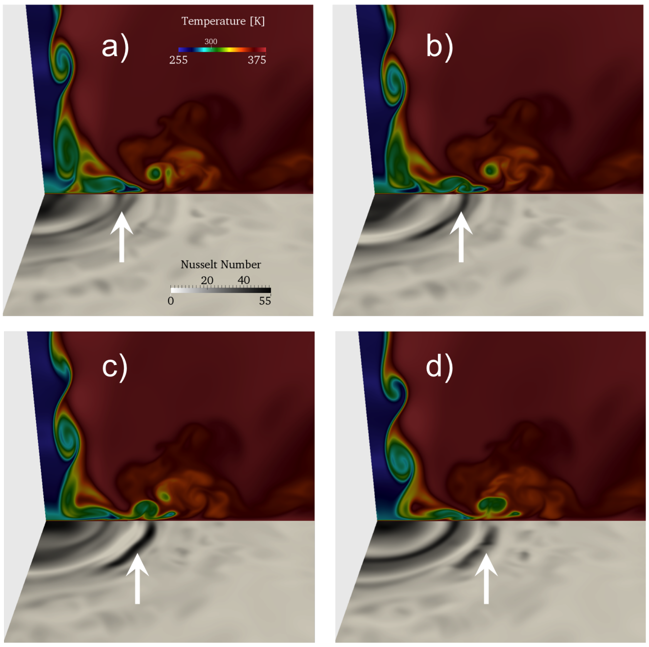


Figure 2: Snapshots of four one another following points in time (a - d) at $Re = 3300$. Slice through the jet axis: temperature. Impingement plate: Nusselt number.

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