DNS-BASED ADJOINT OPTIMIZATION OF THE WALL SHAPE IN TURBULENT CHANNEL FLOW

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Direct Numerical Simulations (DNS) of turbulent channel flow are performed in a computaional domain and for the friction Reynolds number $Re_\tau = 180$ realized in Kim [3] with the aim to reduce the skin friction by controlling the near-wall transport processes based on surface modifications. The latter are determined by solving the adjoint Navier-Stokes equations [2] which depend on time-averaged DNS flow fields. It is well known that the wall-normal momentum transport is organized in sweep and ejection events in the boundary layer which controls skin friction. Bewley *et al.* [1] used adjoint optimization for suction and blowing in turbulent channel flow. They mitigated the effect of the wall-normal transport by opposing near-wall vertical motions of the fluid with an equal and opposite control velocity at the wall. The aim of this work is to achieve this with wall surface modifications. The idea is further to damp the spanwise fluctuations of streaky structures and thus, to reduce the associated skin friction.

Adjoint shape optimization provides surface sensitivities which represent local surface normal displacements which are used to deform the mesh by interpolating the sensitivities to the mesh points with radial basis functions (RBF). As shown in Köthe *et al.* [4], this allows to conserve the mesh quality and the channel volume and avoids the need for remeshing if the deformations are small. Thus, the wall shape is deformed iteratively by continuing the DNS after the surface was modified until a prescribed objective function is minimized.

In the present study, the objective is to minimize the wall shear stress $\tau_w = \mu \frac{\partial v_x}{\partial y}$, where μ denotes the dynamic viscosity and v_x the velocity in streamwise direction. In the context of the used adjoint optimization method, a local skin friction power $P_\tau = F_\tau \cdot v_i$ is used, which is defined at every point of the surface mesh at the wall, where $F_\tau = \int_A \tau_w \, dA$ denotes the friction force. The objective function is then defined as the friction power integrated over a specific time-intervall T,

$$J = \int_T \left[\mu \cdot \frac{\partial v_x}{\partial y} \cdot A_w \cdot v_i \right] dt, \tag{1}$$

with the surface A_w of the individual cell of the surface mesh. The distribution of the wall shear stress at the top wall computed in the DNS and time-averaged over $T = 2 \cdot t^+ = 2 \cdot \frac{t \cdot v_\tau}{\delta}$, where v_τ denotes the friction velocity and δ the half channel height, is presented in figure 1 (middle). The structure correlates well with the time-averaged coherent (streaky) structures, shown in figure 1 (left). The corresponding surface sensitivities are presented in figure 1 (right). They are also well correlated with the wall shear stress, since the Pearson correlation coefficient of these two fields is 0.96 for the top wall and 0.93 for the bottom wall. Thus, we conclude that the applied adjoint shape optimization approach provides surface modification which damp the fluctuations of the streaky structures and reduce the skin friction.

This is concluded since the optimization procedure leads to a reduction of the resulting drag force F_τ by 3% after the first iteration of the shape modification. This will be further iteratvely improved in additional wall modifications steps. Furthermore, simulations will performed also for larger time horizons of the time-averaging, since Bewley *et al.* [1] suggested averaging for $T \geq 25 \cdot t^+$. The results of the above presented research will be presented at the conference.

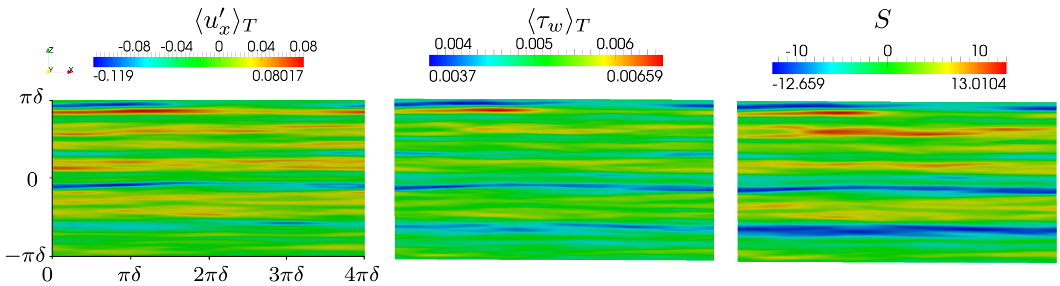

Figure 1. Time-averaged coherent structures at $y^+ = 15$ from the top wall of the channel (left), wall shear stress $\langle \tau_w \rangle_T$ at the top wall of the channel (middle) and the resulting surface sensitivities S (right).

References

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