Development of Turbulent Inflow Methods for the High Order HPC Framework FLEXI

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Project "hpcdg"

FLEXI performance on HAWK

To analyze the impact of the architecture of HAWK, the performance analysis was first carried out on all available cores (stride=1) and in a second step, while using only every second available core (stride=2), see Fig. 1. This artificially increases the available memory bandwidth per active core. The results in Fig. 1 indicate that the case with stride=2 gains about 30 % in performance compared to the stride=1 case.

The lifting procedure was redesigned to compute only the gradients of the variables which are actually required to compute the parabolic fluxes of the Navier-Stokes-Fourier equations. It reduced the memory footprint of the lifting procedure by about a fifth and improved the overall performance of FLEXI.

The function call of two frequently called functions, namely the Riemann solver as well as the solver for the two-point volume split flux, was optimized. We introduced a two step compilation process to employ profile-guided optimization (PGO). By using PGO, the aforementioned functions get optimized by the compiler and the cache usage is improved. In 1c and 1d the results with the optimized code version using both stride=1 and stride=2 are depicted. A comparison of 1a with Fig. 1c demonstrates a performance improvement by about 25 % in case of an optimal load and even up to 40 % for high loads.

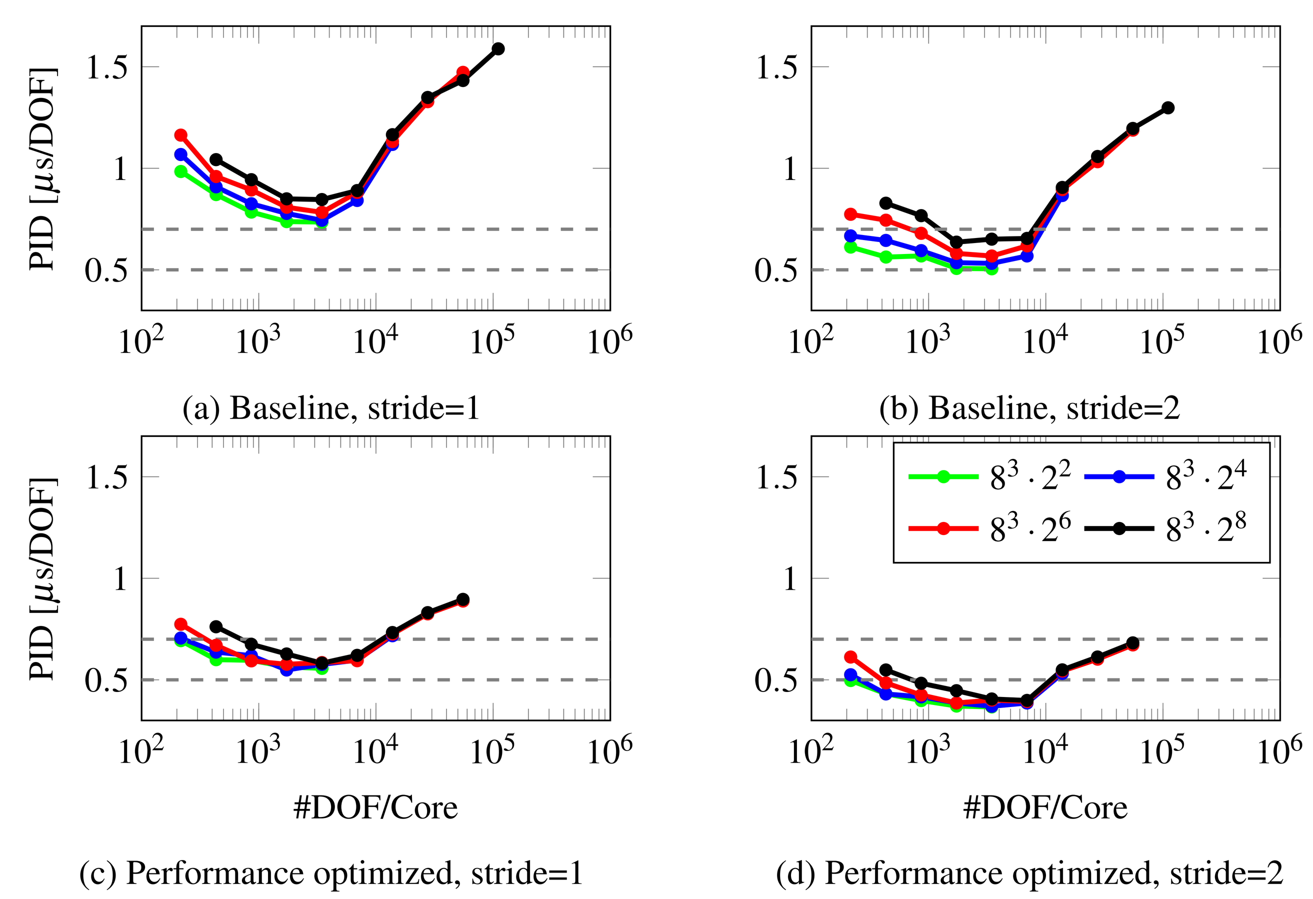

Figure 1: Results of the scaling analysis for different meshes and loads. Four different cases are investigated: the baseline version of FLEXI as described in Krais et al. [3] and the optimized version for HAWK with a stride of 1 and 2 for each version. The legend lists the number of elements of the investigated meshes.

Recycling-Rescaling Anisotropic Linear Forcing (RRALF)

The RRALF method by Kuhn et al. [4] is a combination of the recycling-rescaling method for zero pressure gradient (ZPG) boundary layer flows by Lund et al. [5] and the anisotropic linear forcing introduced by de Laage de Meux et al. [1]. Thus, RRALF relies on the Navier-Stokes equations for physical turbulence production but adds a forcing zone in front of the recycling plane to break the limitation to ZPG boundary layers and drive the solution towards the desired boundary layer profile as seen in Fig. 2. The rescaling follows [5] by splitting the boundary layer in an inner and outer region and reconstructing the rescaled profile using

$$u_{i,in} = \left[(\bar{u}_i)_{in}^{inner} + (u_i')_{in}^{inner}\right]\left[1 - W(\eta_{in})\right] + \left[(\bar{u}_i)_{in}^{outer} + (u_i')_{in}^{outer}\right] W(\eta_{in}),$$

where u_j is the corresponding component of the instantaneous velocity field, $\bar{[\,]}$ and $[\,]'$ denoting mean and fluctuating quantities, and $W(\eta_{in})$ is a blending function. The ALF volume forcing term is taken from [1], which yields

$$\frac{\partial \rho u_i}{\partial t} = R(u_i) + \rho f_i$$

for each of the momentum vector components $i = 1, 2, 3$, where R represents the spatial DG operator and f_i the ALF vector given as $f_i = A_{ij} u_j + B_i$. A_{ij} and B_i denote the tensors for the Reynolds stresses and the mean velocity forcing, respectively.

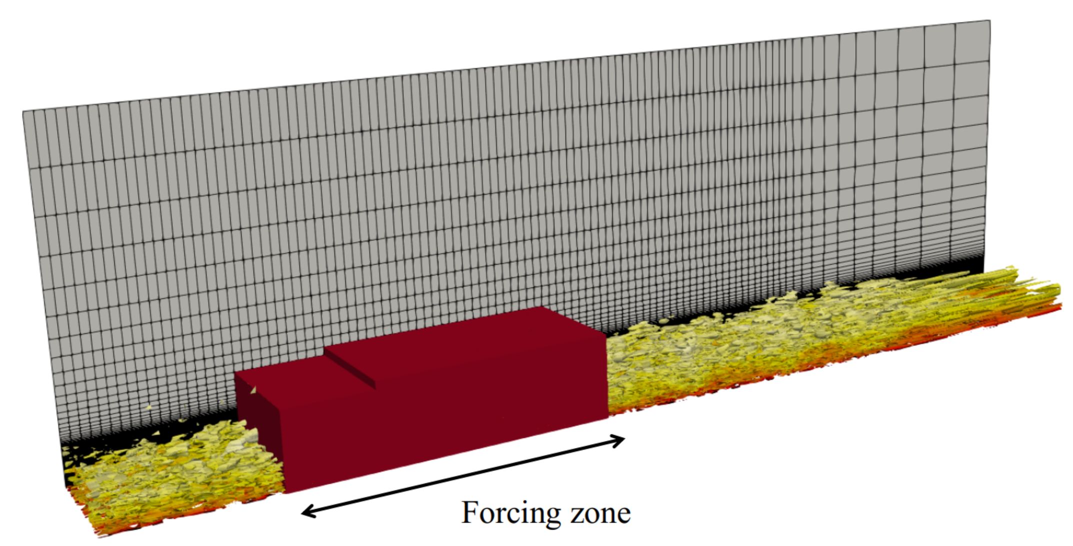

Figure 2: Q-criterion of the turbulent structures colored by the velocity magnitude. The red region represents the zone where the ALF is enforced. The background mesh is also presented up to $10.5\delta_{99}$ in the wall-normal direction.

Subsonic turbulent flat plate

Two simulations of a weakly compressible ($Ma = 0.3$) turbulent flat plate were carried out. First, a tripped turbulent boundary layer simulation, starting at $Re_\theta = 750$ up to $Re_\theta = 2800$, was conducted. These simulation results were used as target data for a zonal LES of the rear half of the flat plate. The zonal LES had the same mesh resolution and resolved the boundary layer from $Re_\theta = 1800 - 2800$. The simulation setup is depicted in Fig. 3.

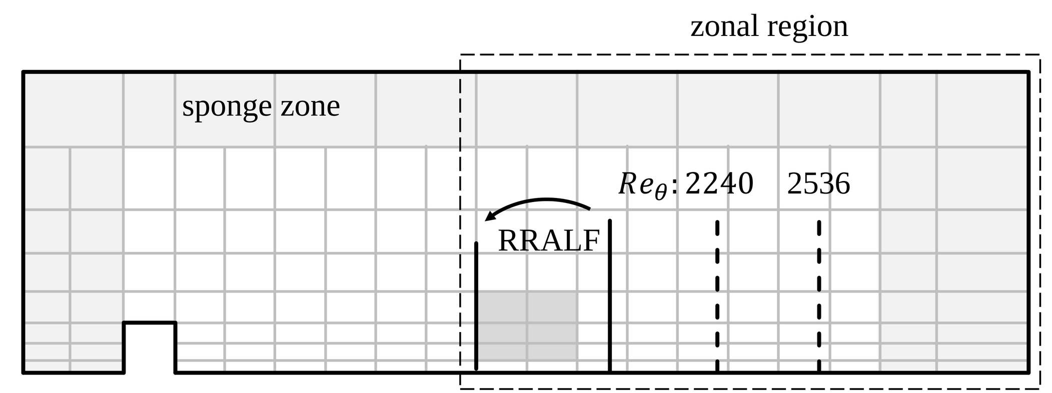

Figure 3: Sketch of the mesh used for the tripped and zonal simulation of the turbulent flat plate.

Fig. 4 depicts the first and second order turbulence statistics at $Re_\theta = 2240$ and $Re_\theta = 2536$ within the zonal region, for which reference data from Eitel-Amor et al. [2] is available. The time-averaged streamwise velocity in Fig. 4 (left) displays a good agreement with the reference. The second order turbulent statistics in form of the normal stresses are illustrated in Fig. 4 (right). For both Reynolds numbers, the tripped and the zonal LES show again good agreement with the reference.

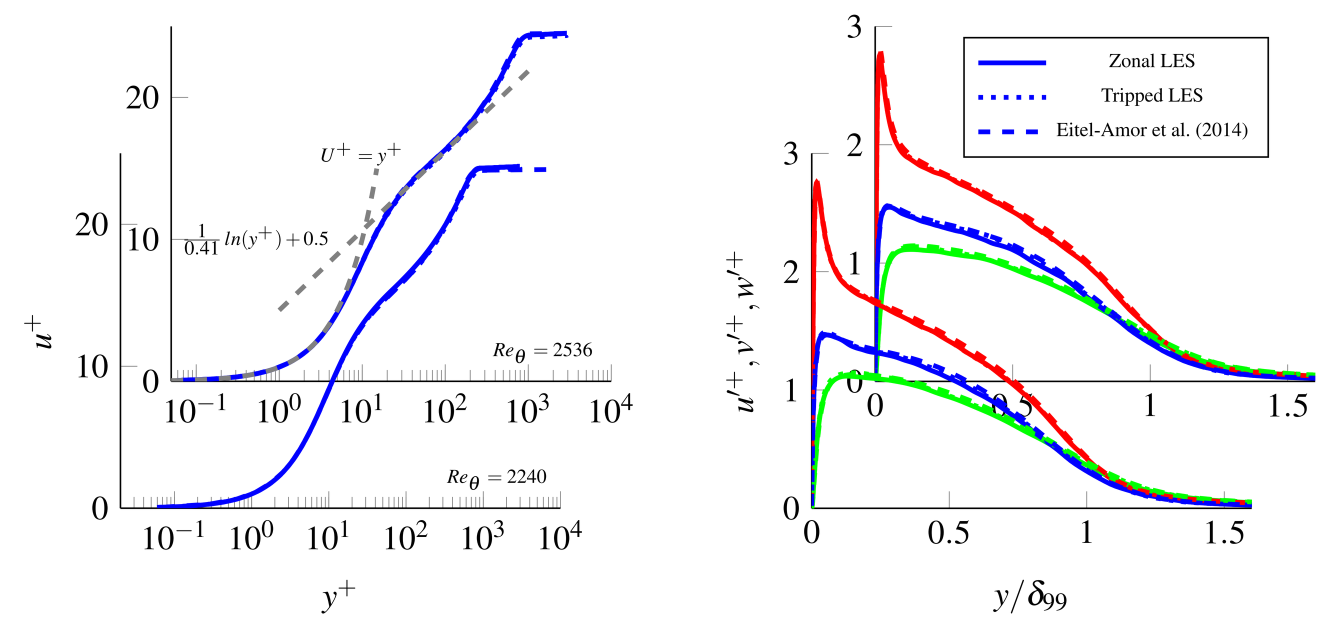

Figure 4: Comparison of the mean velocity $u^+ = u/u_\tau$ (left) and the Reynolds fluctuations (right) at $Re_\theta = 2240$ and $Re_\theta = 2536$ for the tripped and the zonal turbulent flat plate with a numerical reference from Eitel-Amor et al. [2]. The Reynolds fluctuations $u'^+ = \sqrt{\overline{u'u'}}/u_\tau$, $v'^+ = \sqrt{\overline{v'v'}}/u_\tau$ and $w'^+ = \sqrt{\overline{w'w'}}/u_\tau$ are presented by red lines (–), green lines (–) and blue lines (–), respectively.

References

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