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Large eddy simulation of a transitional flow over a backward facing step with boundary layer manipulations

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We consider a backward facing step channel and we investigate the flow for a Reynolds number of 3000 built with the velocity u_0 of the block inflow profil and the step height H (see fig. 1). The top of the channel is considered as a slip wall and in the lateral direction a periodic behavior is assumed. With the aim of the drag reduction or a decreasing reattachment lenght in the wake of the step acoustic manipulations of the boundary layer in front of the step were performed by experiments and numerical simulations ([1], [2] and [5]). It was found a good agreement of the experimental and numerical results, especially in the case of the reattachment length but also related to the mean velocity field and the rms-profiles. The numerical investigations are done as direct numerical simulations and large eddy simulations. For the direct numerical simulations about 10 million grid points are needed for the spatial discretization. In the case of the large eddy simulations it is possible to work with about 500 thousands of spatial grid points. We use a subgrid scale model of Germano type following Akselvoll/Moin [3]. During the numerical simulations the sufficiency of LES to describe the flow over the backward facing step physical correctly could be shown.
Beside the accoustic boundary layer manipulation over slits with certain frequencies experiments are done with oblique backward facing steps or with moving boundaries to simulate oblique geometries. Based on the experiences of the above discussed numerical simulation of a straight backward facing flow large eddy simulations with moving boundaries are under consideration.
We investigate both a moving upstream boundary in front of the step (lateral velocity v_u) and a moving boundary behind the step in the downstream region of the bottom of the channel (lateral velocity v_d, see fig. 2). The simulations are done for a wide range of lateral boundary velocities, i.e. from $v_{lateral} = 0.5\,u_0$ to $v_{lateral} = 2.0\,u_0$ with u_0 as the inflow profile velocity.

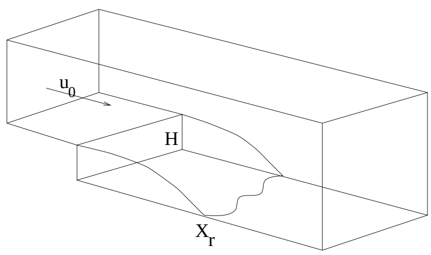

Figure 1: channel situation

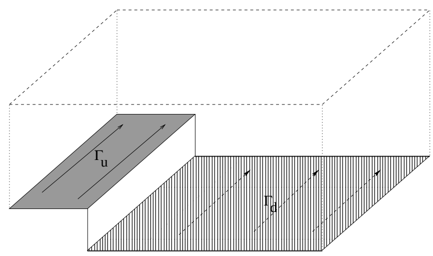

Figure 2: Γ_u and Γ_d as a moving boundaries

In fig. 3 the mean wall shear stress velocity u_τ of the case $v_u = 2\,u_0$ and $v_d = 0$ is shown compared to those of the neutral case $v_u = 0\,u_0$ and $v_d = 0$ in fig. 4.

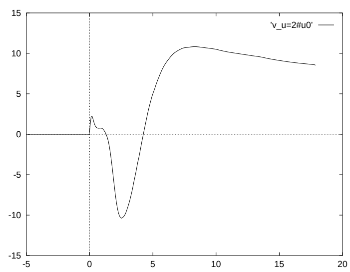

Figure 3: u_τ of the emulated oblique step flow

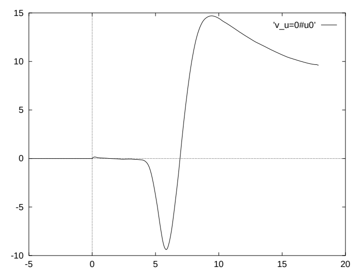

Figure 4: u_τ of the neutral step flow

The numerical simulations are done with a finite volume method on staggered grids which is parallelized on a Cray T3D/T3E using fast Cray-specific shared memory transfer utilities or the platform independend MPI library ([4]). The method is of second order in space and time. The mass conservation per time step was realized by a pressure-velocity iteration method.
The parallelized numerical model (DNS/LES) was validated by comparisons of the numerical DNS/LES results of [5] and the experimental data of [1] and [6]. The following figures 5-8 show the result of comparison for the mean velocities and the rms-values. For these comparisons a neutral, non-manipulated backward facing step flow for the transitional Reynolds number 3000 was considered. The experimental results were produced by LDA-measurements.

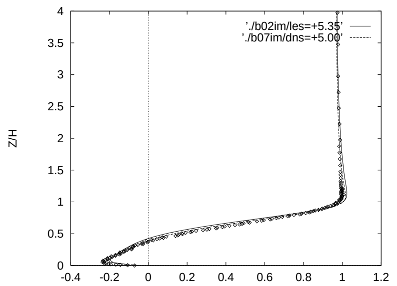

Figure 5: u_{mean} at $x = 5H$

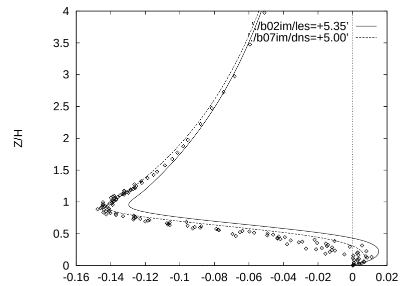

Figure 6: v_{mean} at $x = 5H$

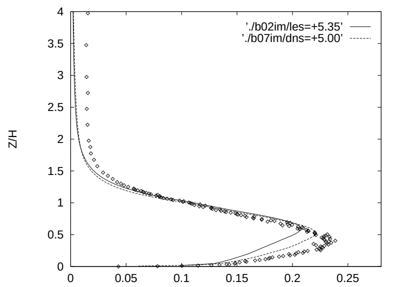

Figure 7: u_{rms} at $x = 5H$

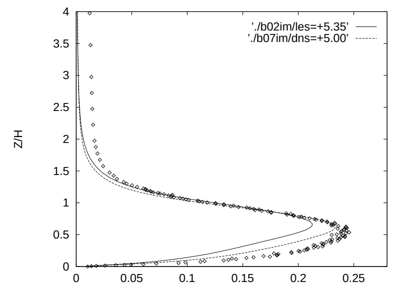

Figure 8: u_{rms} at $x = 5H$

The performance of the parallelized code ($1.3 * 10^7$ gridpoints, 100 timesteps, 25 pressure-velocity iterations) on different mpp systems is shown in the table 1.

system	#procs		time t [sec]	mflops	t_{C90}/t	$S_p = t_{J90(1)}/t$
J90	1		16428	92	0.27	1.00
J90	4		4173	357	1.03	3.94
J90	8		2244	673	1.95	7.32
J90	16		1390	1087	3.15	11.81
C90	1		4380	338	1.00	
system	#procs	$\text{proc}_X * \text{proc}_Y$	time t [sec]	mflops	t_{C90}/t	$S_p = t_{T3D(32)}/t$
T3D	32	8 * 4	3329	443	1.31	1.00
T3D	64	8 * 8	1671	886	2.62	1.99
T3D	128	16 * 8	871	1700	5.03	3.82
T3D	256	16 *16	437	3387	10.02	7.61

Table 1: *Performance of the FV code on different mpp systems*

The results of the reattachment lenght reduction in the case of the moving upstream boundary in front of the step show a good agreement with the known experimental measurements. The large eddy simulations with the moving boundary behind the step are in the beginning and the first analysis shows no remarkable influences of the lateral boundary velocity v_d to the position of the reattachment point X_r. A significant reduction of the reattachment lenght was not found. The comparison of the numerical results and the experiments of such a channel flow with a moving channel bottom behind the step, which are done now, will be discussed.

References

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