LES studies o the interaction of a free shear layers with a proximate wall in post-reattachment recovery and a plane turbulent wall jets

A. Dejoan and M.A. Leschziner
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Many wall-bounded turbulent flows are characterized by a complex interaction between the outer shear layer, the structure of which is similar to a free shear layer, and an inner layer, which is essentially a perturbed boundary layer. Examples in which such an interaction occurs are separated flows recovering from reattachment, wall jets used in the context of wall cooling, heating and separation control, and impinging jets used to enhance heat transfer.

Two different flow configurations presenting related interactions are considered in the work summarised herein, Fig. 1. One is a wall jet and the other a backward-facing-step flow. In the latter, interest is focused especially on the interaction in the post-reattachment-recovery region and the near-wall region within the lower portion of the recirculation zone. In both these areas, an 'outer' shear layer interacts with the boundary layer, and is of interest to explore whether these have features akin to those in a wall jet. A specific objective is to gain insight into why most RANS closures do not represent post-reattachment recovery well. To this end, second-moment budgets have been examined, and used in a-priori studies of closures, the latter reported in Dejoan et al. (2006). Preceding the work summarised herein, the flow and turbulence physics of wall jets, with a real frictional wall as well as frictionless wall, were studied in detail by means of highly resolved LES (Dejoan and Leschziner (2007), (2007[1])). The emphasis of these studies was to identify the processes by which the near-wall layer interacts with the separated (free-shear) layer above it, and on separating frictional from inertial effects on turbulence features at the wall. The present study targettedv the identification of generically common features between the wall jet and interacting shear layers in separated flow.

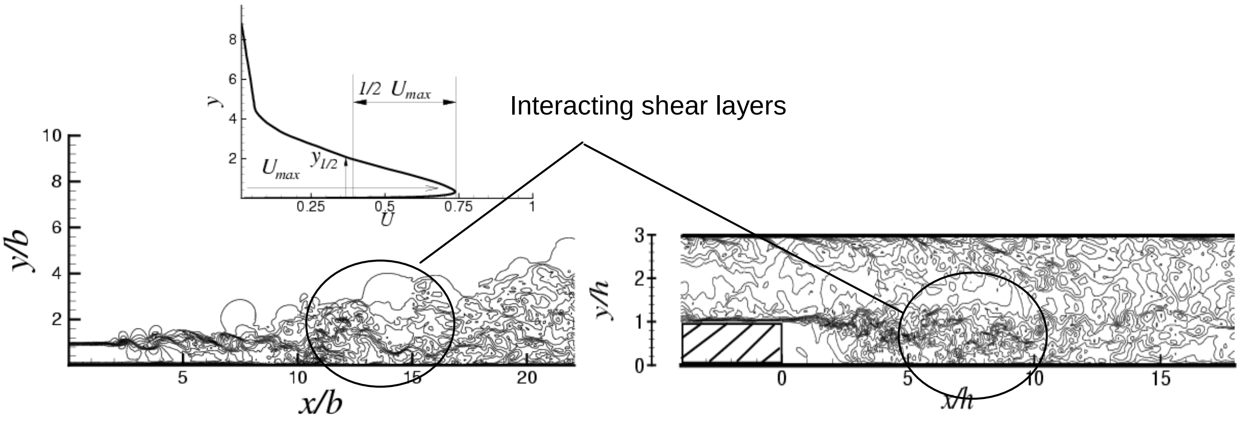

Fig1: Related flow geometries examined

The back-step flow is at a Reynolds number $Re = U_c h / \nu = 3700$, at conditions identical to the experimental configuration of Yoshioka et al. (2001). The computational domain extended from 4*h* (*h* being the step height) upstream of the step to 18*h* downstream. The spanwise direction is homogeneous and is 4/3π deep. The grid contained 2 million nodes, resulting in a maximum ratio of the grid length scale, Δ, to the Kolmogorov scale, η, not exceeding 7 throughout the domain. The maximum distance of the wall-nearest computational node from the wall was $y^+ < 1$ at both lower and upper walls, and the cell-aspect ratio was, typically, $\Delta y^+ / \Delta x^+ / \Delta z^+ = 0.6/18/10$ at the wall and

2.5/18/10 in the outer shear layer. A fully-developed channel-flow precursor computation was performed for the inlet conditions prescribed at 4*h* upstream the step.

The plane turbulent wall jet is at a Reynolds number $Re = U_o b/\nu = 9600$, where U_o is the inlet velocity and *b* the slot height. For this geometry, two cases were simulated. In one, the jet developed along a real wall and in the other along a frictionless wall, equivalent to a zero-shear, non deformable free surface. The intention is to permit effects arising from wall-blocking and near wall-shear effects to be distinguished or separated within the whole interaction process between the outer shear layer and the wall. The real jet simulated corresponds to the experimental study of Eriksson et al. (1998). In both jet flows, the domain extends from the wall to 10*b* above it and to 22*b* in the streamwise direction. The grid contained 8 million cells and the ratio Δ/η was typically 5-10. For the real jet, the near wall cell-aspect ratio was, typically, $\Delta y^+/\Delta x^+/\Delta z^+ = 1.2/24/24$ the wall-nearest grid node lying at y^+=0.6. More details on the wall jet flows can be found in Dejoan and Leschziner (2007[2]).

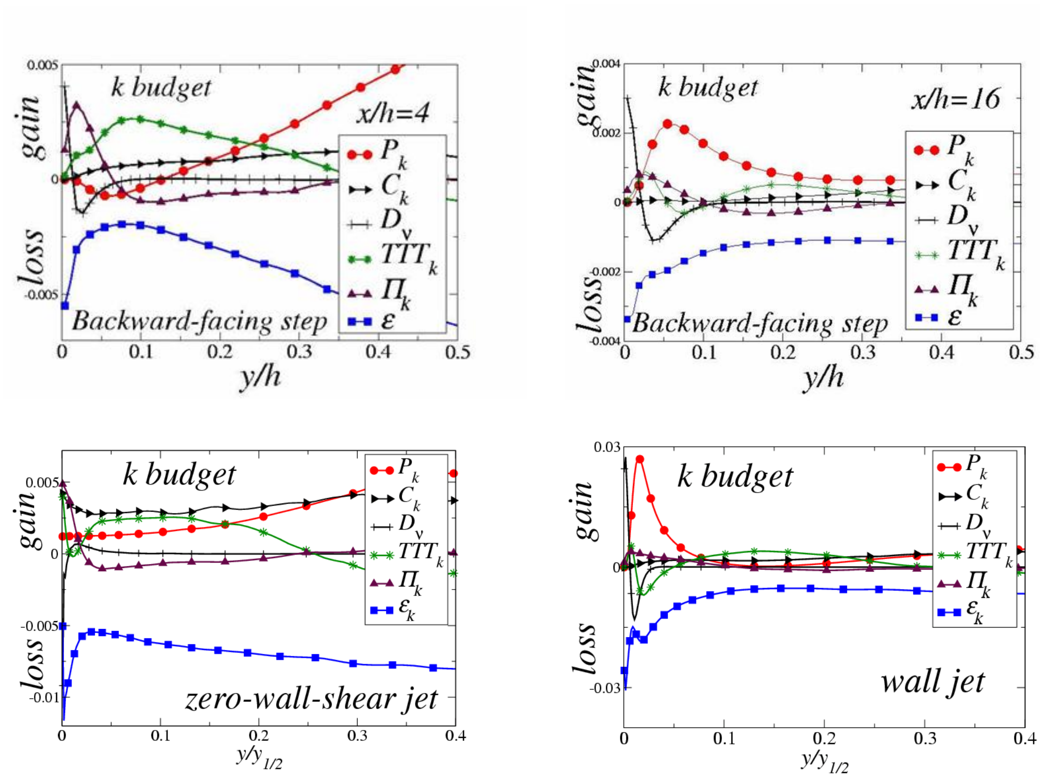

Fig. 2: Budgets of turbulence energy: *P*-production, *C*-convection, D_v-viscous diffusion, *TTT*-turbulent diffusion, *II*-velocity-pressure correctation, ε–dissipation

The present work aims to examine the extent to which the mechanisms involved in the interaction between the free shear layer and the lower wall downstream a backward-facing step are related to those encountered in a wall jet. To this end, comparisons are undertaken of the Reynolds stresses budgets for the backward-facing step at different locations downstream the step against the budgets of the wall jets computed in the self-similar region. One of several interesting observations is conveyed by Fig. 2, which shows the budgets of the turbulence energy for the backward-facing step flow at two streamwise positions downstream the step, *x/h*=4 and *x/h*=16, located in the recirculation and post-reattachment region, respectively (reattachment occurs at *x/h*=7), against the budgets for the finite-wall-shear and zero-wall-shear jets in the self-similar region. It is observed that, with convection aside, which vanishes at the wall of the backward-facing step but is non-zero for inviscid-wall jet, the budget of *k* in the recirculation region is close to that for the frictionless-wall jet. Downstream of reattachment, production becomes increasingly dominant and the budget of *k* becomes similar to the real jet. Fig. 3 shows the budgets of the wall-normal Reynolds stress. A common feature observed for the three flows is the large contribution of turbulent diffusion in the near-wall region, balanced by dissipation and pressure-velocity correlation. The last contribution is slightly negative for the real jet, and exhibits a pronounced negative peak for the two other flows, which goes hand-in-hand with a gain due to turbulent diffusion. Thus, the latter process is of considerable importance, and its closure may require more careful attention than is normally given to it. Further results and a more detailed analysis are provided in Dejoan and Leschziner (2007).

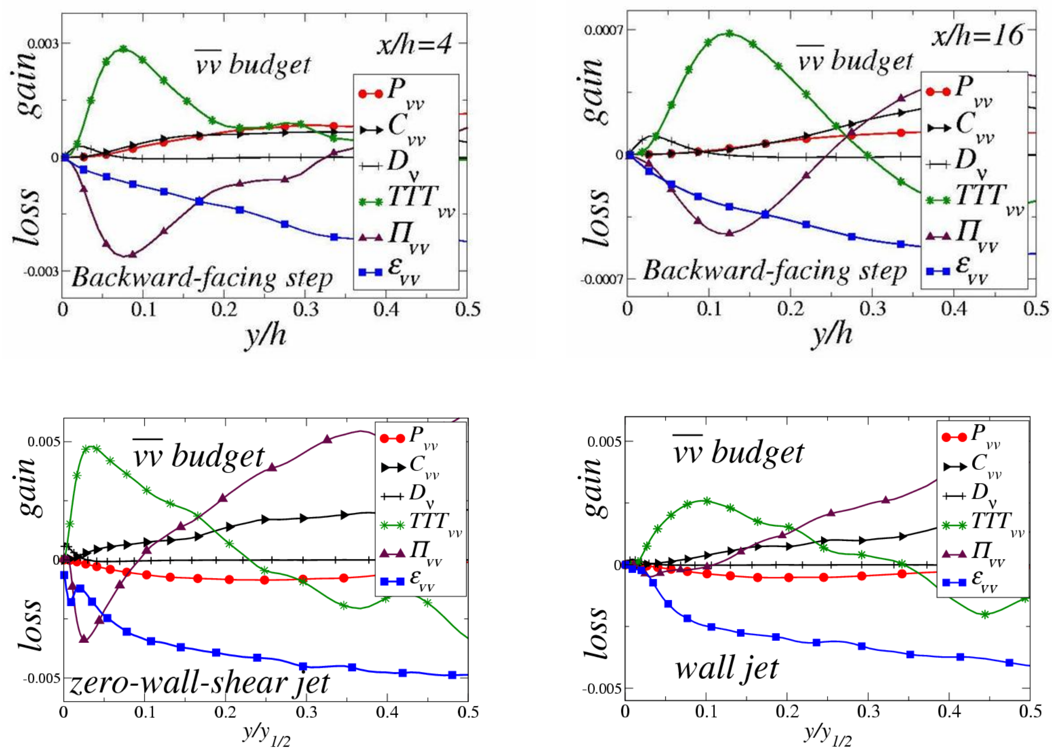

Fig. 3: Budgets of the wall-normal Reynolds stress

References

Dejoan, A. and Leschziner, M.A., (2005), "Large eddy simulation of a plane turbulent wall jet", Physics of Fluids, 17, No.2, paper 025102.

Dejoan, A. and Leschziner, M.A. (2007), Separating the effects of wall-blocking and near-wall shear in the interaction between the wall and the free shear layer in a wall jet, Physics of Fluids, 18, paper 065110.

Dejoan, A. and Leschziner, M.A. (2007), On the near-wall structure in reverse-flow and post-reattachment recovery regions of separated flow and its equivalence to the structure in wall and free-surface jets, J. of Turbulence, 8 (14), pp. 1-25.

Dejoan, A., Wang, C. and Leschziner, M.A., (2006), Assessment of turbulence models for predicting the interaction region in a wall jet by reference to LES solution and budgets, Invited paper, Flow, Turbulence and Combustion, Flow, Turbulence and Combustion, 77, 229-255.

Eriksson, J. G., Karlsson, R. I. and Persson, J. (1998), An experimental study of two-dimensional plane turbulent wall jet, Expts. in Fluids, 25, pp. 50-60.

Yoshioka, S., Obi, S., and Masuda, S. (2001), Turbulence statistics of periodically perturbed separated flow over a backward-facing step, Int. J. Heat and Fluid Flow, 22, pp. 393-401.