ISSUES IN HYBRID LES-RANS AND COARSE GRID LES OF SEPARATED FLOWS

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Abstract Turbulent channel flow with periodic hill constriction is studied computationally by various research groups. Different computer codes are used employing large eddy simulation (LES) and hybrid LES-RANS simulation strategies including the most popular one, detached eddy simulation (DES). It is demonstrated that though performed on the coarse grid ($\approx$ 1 Mio. cells), hybrid LES-RANS methods are capable of reproducing the mean flow and turbulence features of a quality comparable to the highly resolved LES ($\approx$ 13 Mio. cells). The issue of the LES-RANS interface appears to be crucial for exploiting advantages of both RANS and LES strategies in different regions of the flow.

INTRODUCTION

The flow over a periodic arrangement of smoothly contoured hills [?] has been extensively studied over the past few years [?]. Recently, this flow configuration at Re=10 595 has been selected as a common test case within the French-German research group 'Large eddy simulation of Complex Flows'. Originally based on the experiment of Almeida et al. [?], the numerical benchmark case has been modified in order to overcome geometric constrictions present in the experiment [?]. A corresponding experiment is presently designed at the TU Munich so that experimental data will be available soon. New reference solutions were obtained as well by the French-German research group [?]. That includes a highly resolved large eddy simulation (LES) at Re=10 595 (using 13.6×10^6 grid cells) and direct numerical simulation (DNS) at Re=2800 and 5600 (using 48×10^6 and 233×10^6 grid cells, respectively). Accurate LES predicitons of wall-bounded flows are limited to lower Reynolds numbers due to extremely high resolution requirements in the near-wall region. Various hybrid LES-RANS strategies were proposed to get rid of this limitation. The most popular hybrid LES-RANS method is detached eddy simulation (DES) [?] based on the one equation Spalart-Allmaras (S-A) RANS model. In this non-zonal approach the interface between RANS and LES region is dictated by the adopted grid. If performed on a suitable grid, DES predictions are typically expected to be superior to the ones obtained by the Reynolds-averaged Navier-Stokes (RANS) method. However, serious deterioration of the predictions may occur if the LES-RANS interface resides at either too large or too close distances from the wall. Noting that the S-A model has been tuned for external aerodynamic flows, it is interesting to examine DES performance in a wall-bounded complex flow such as the periodic hill configuration. The present work investigates performance of LES and DES for the hill flow at Re=10 595 using coarse grids limited to 1 Mio. cells. Different computer codes used by independent groups are employed to predict the flow by DES performed on the same reference grid ($160 \times 100 \times 60$). Important issues in DES and coarse grid LES are studied including the influence of the position of LES-RANS interface, spanwise resolotion and sub grid scale (SGS) modeling. Another hybrid LES-RANS method using a unique model is proposed and tested on the given benchmark case.

COMPUTATIONAL DETAILS

Four computer codes: LESOCC, ISIS, MGLET and FASTEST were used to generate predictions of the periodic hill flow. The codes solve the incompressible Navier-Stokes equations on body-fitted, non-orthogonal grids (MGLET employs immersed boundary method) by finite-volume methods with collocated arrangement of the Cartesian velocity components. Second-order central differencing is used to approximate convective and diffusive terms. Different second-order time integrations are used. Detailed descriptions of the codes will be provided in the full-length paper. The reference grid used in all computations consists of 960 000 cells ($160\times100\times 60$). The resolution in the wall-normal direction provides $y^+ < 1$ at the nodes closest to the lower wall along largest portion of the computational domain ($L_x = 9H, L_y = 3.035H, L_z = 4.5H$, H being the hill height). Relatively coarse streamwise and span-

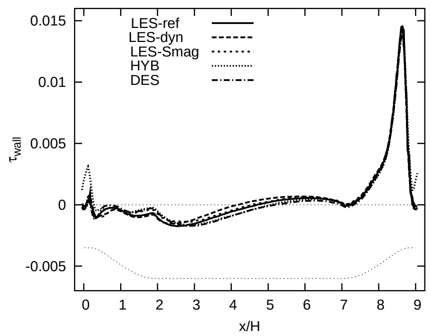

Figure 1: Comparison of wall shear stress predictions with LES, DES and hybrid LES-RANS model.

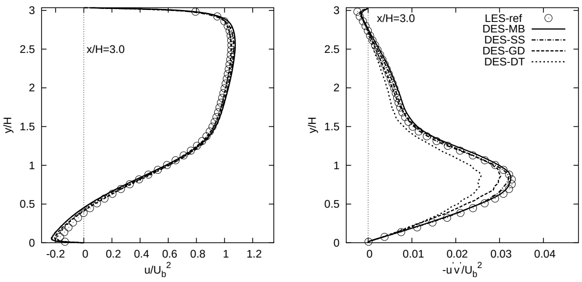

Figure 2: Streamwise velocity (left) and shear stress (right) profiles obtained by different codes.

wise resolutions are intentionally adopted so that the RANS region in the framework of DES covers the first 7-9 cells (lower wall) and 4-5 cells (upper wall) in the wall-normal direction. Additional simulations with coarser resolutions in the wall-parallel directions are performed to assess the influence of the position of LES-RANS interface on DES performance. The standard Smagorinsky model along with its dynamic variant is used in the framework of LES. The original DES formulation based on the S-A model is used, except the representative filter size. In addition to the original DES filter defined as $max(\Delta x, \Delta y, \Delta z)$, the geometric mean proposed by Smagorinsky, i.e., $(\Delta x \times \Delta y \times \Delta z)^{(1/3)}$ is also used. In addition to DES another non-zonal method employing a one-equation model based on the transport equation for kinetic energy of turbulence (Rodi et al [?] is investigated. This equation governs the total turbulent kinetic energy k_{tot} in RANS mode and the modeled turbulent kinetic energy k_{mod} in LES mode. Different dynamic switching criteria based on k were tested to define the interface between RANS and LES. More details will be given in the final manuscript.

RESULTS

Though performed on the coarse grid, all simulation strategies employed in this study appear to be capable of reproducing the main flow features as demonstrated in Fig.1 which displays wall shear stress predictions for the lower wall. Overall good agreement is observed comparing the DES results generated by different codes using the same reference grid. Some discrepancies are still visible, mainly due to differences in the important model parameters such as the DES filter width. This is illustrated in Fig.2 which shows streamwise velocity and shear stress profiles across the recirculation zone at the location x=3H. Fig.3 shows DES predictions of the wall shear stress obtained on different grids. Noting minor differences in the predicted separation locations, reattachment points are predicted as $5.07H(DES-160\times100\times60)$, $4.48H(DES-160\times100\times30)$ and $5.24H(DES-80\times100\times60)$, the reference LES reattachment being at 4.66 H. The issue of the LES-RANS interface appears to be crucial for exploiting advantages of both RANS and LES strategies in different flow regions.

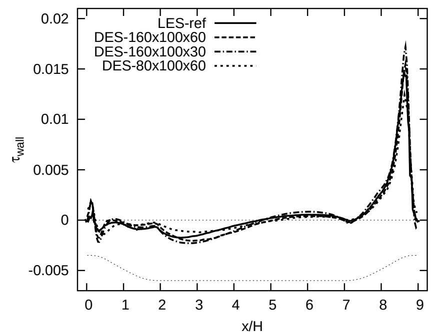

Figure 3: Comparison of wall shear stress predictions obtained by DES on different grids.

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