PANS simulations: low versus high Reynolds number approach

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ABSTRACT

The application of high fidelity turbulence models for industrial problems, such as cavitation calculations, is mostly focused on the use of *hybrid* models such as DES-based models. These models switch between RANS and LES based on the local grid size and wall distance, with the aim of improving the accuracy compared to full RANS. However this approach may lead to commutation errors in the transition between the two zones, and is highly grid dependent due to the zonal formulation. Also numerical error quantification is difficult due to the entanglement of the modelling and discretization error. *Bridging* models, such as Partially Averaged Navier-Stokes (PANS), are an alternative approach without these problems. The PANS model can operate at any degree of physical resolution, independent of the grid, by setting the modelled-to-total ratios of turbulence kinetic energy (f_k) and dissipation (f_ε) [1]. In literature, the model is applied almost exclusively using $f_k \ll 1$ and $f_\varepsilon = 1$ (known as the high Reynolds number approach). Here it is assumed that the grid cut-off is not placed in the dissipation range and that the dissipation occurs entirely at the unresolved scales. This is valid if there is a clear separation between the large energy containing scales and the small dissipative scales (the inertial subrange follows Kolmogorov's law) [2, 1]. For low Reynolds number flows where the scales overlap, or for a high Reynolds number flow with a high physical resolution (low f_k), part of the dissipation should be resolved as well, so f_ε should be lower than 1. To investigate the performance of the model the actual resolved turbulence kinetic energy will be compared with the input values, for different f_k and f_ε.

Although most maritime applications are high Reynolds number flows it is not unlikely that in some cases high physical resolutions are required, i.e. low f_k values will be applied. For low Reynolds numbers an often mentioned approach is for keep $f_k = f_\varepsilon$, whereas for moderate Reynolds numbers $f_k < f_\varepsilon < 1$ [3, 2]. Pereira et al. [4] state that if $f_k = f_\varepsilon$ the only change with respect to the underlying RANS model is an increase of the effective diffusion coefficient and cross-diffusion term; using this approach vortex shedding for a cylinder was underpredicted. In contrast Lakshmipathy et al. [2] obtained satisfactory results for the same test case using a finer grid, indicating a grid dependency. To evaluate the effect of modifying f_ε, in the current work PANS is applied to a turbulent channel flow with a moderate Reynolds number, $Re_\tau = 395$ ($Re_b = 13800$), using both approaches. The results are compared to Direct Numerical Simulation (DNS) reference data by Moser et al. [5]. The results of the high Reynolds number approach were previously presented, together with LES results, in Klapwijk et al. [6], where full details of the numerical setup can be found. To maintain a distinction between modelling and numerical error, f_k and f_ε are kept constant in time and space.

Figure 1 shows a very different behaviour between the two approaches. The velocity plots, Reynolds stress components and turbulence kinetic energy spectrum show a reasonable match with the DNS reference data. The low Reynolds number approaches shows discrepancies in the averaged velocity and underpredicts the Reynolds stress components, in line with the results by Pereira et al. [4]. The turbulence kinetic energy spectrum shows an increasing energy with decreasing f_k but is too low for all simulations.

It is therefore observed that for this case PANS with $f_k = f_\varepsilon$ indeed adds excessive diffusion.

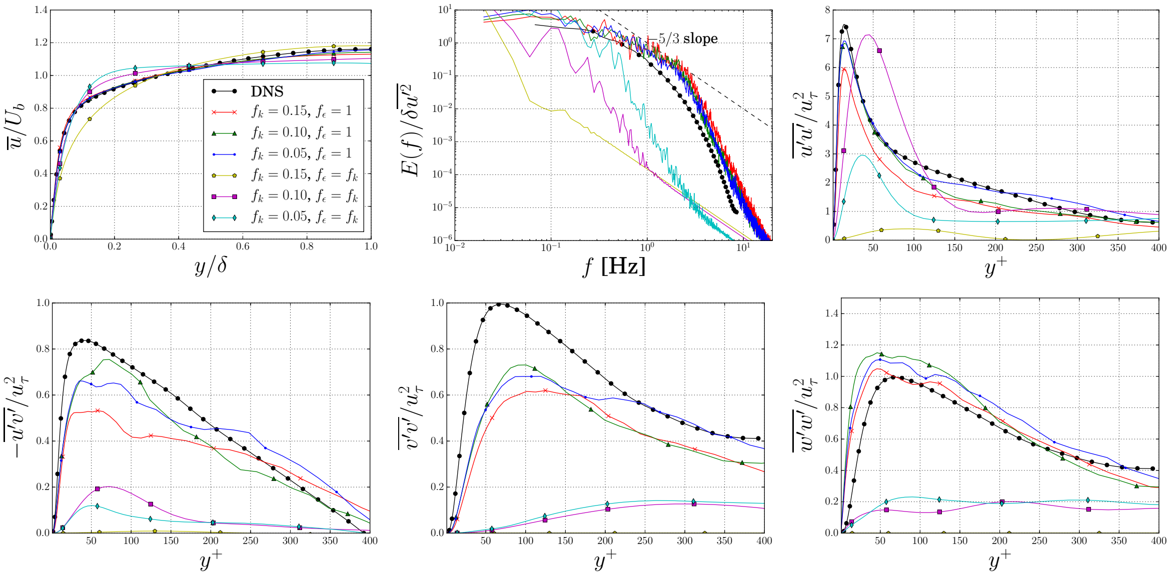

Figure 1: Velocity profiles ($\overline{U}$), (a), turbulence kinetic energy spectra ($E(f)$), (b), normalised Reynolds stress profiles (Re_{ij}), (c-f).

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