Detached Eddy Simulation with Finite Elements

Implementation and Validation of a hybrid RANS-LES model in the parallel Computational Mechanics Code ALYA

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Fluid simulation for complex flows like those needed in aeronautics with high Reynolds numbers and massively separated flows demand hybrid methods. While large-eddy simulation (LES) is too costly in boundary layers, Reynolds-averaged Navier-Stokes modeling (RANS) does not represent the physics well enough to handle large separation regions, e.g. past vehicles. Detached-eddy simulation (DES), first proposed in 1997 [1], is a hybrid RANS-LES-approach. DES avoids, in contrast to other hybrid techniques, an a-priori selection of zones, which is a crucial point for real world applications.

We implemented a recently improved version [2], resistant to the well known DES problems log layer mismatch (LLM) and grid-induced separation (GIS), into the parallel computational mechanics code *Alya* hosted at the Barcelona Supercomputing Center. As underlying RANS model we used the shear stress transport model [3]. DES is classically used with finite volumes. *Alya* is however a finite element code. For this combination not many experiences have been published yet. We introduced a blending of the algebraic subgrid scale stabilization [4] for the Navier-Stokes equations. This corresponds to the well-known blending of the discretization scheme for the convective term usually used for DES finite volumes codes [5]. The blending also gave rise to a new calibration of the DES Smagorinsky constant to $C_{DES} = 0.50$.

We tested the implementation with three scenarios. First, a decaying isotropic turbulence at $Re = 4.209 \cdot 10^5$ which we used for the calibration as it yields DES to act as pure LES. Second, a turbulent channel at $Re_\tau = 395$ and $Re_\tau = 18000$. We compared the lower Reynolds number case with DNS reference data as well as with LES results and the higher Reynolds number case with the Reichardt correlation. The improved DES approach outperformed hereby the more classical variant of DES as well as LES with a similar grid resolution. For $Re_\tau = 18000$ we only needed a grid with twice as more nodes than for $Re = 395$ in order to obtain the same quality of results. Finally, we simulated the flow over a 2D wall-mounted hump at $Re = 9.36 \cdot 10^5$, which we compared against RANS results. DES, being hereby not more costly, showed also results of equal quality. However, our DES method, contrary to RANS, was able to capture the time-dependent motion. The work was detailed documented in [6].

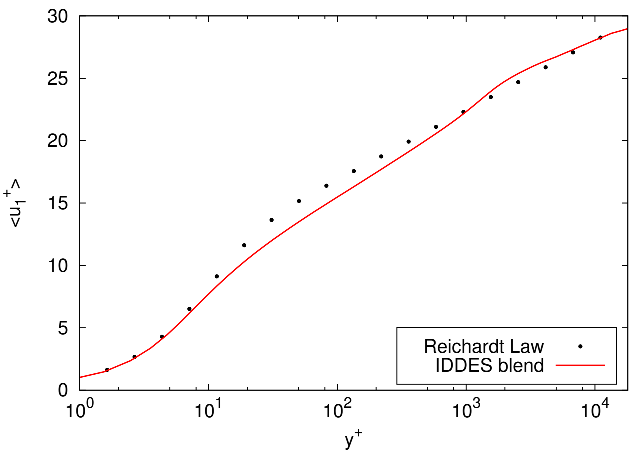

Figure 1: Time and space-averaged velocity profile in streaming direction $\langle u_1^+ \rangle$ for the turbulent channel at $Re_\tau = 18000$. We compared the stabilization-blended improved delayed DES with the Reichardt correlation. The grid consisted of $81 \times 125 \times 61$ nodes.

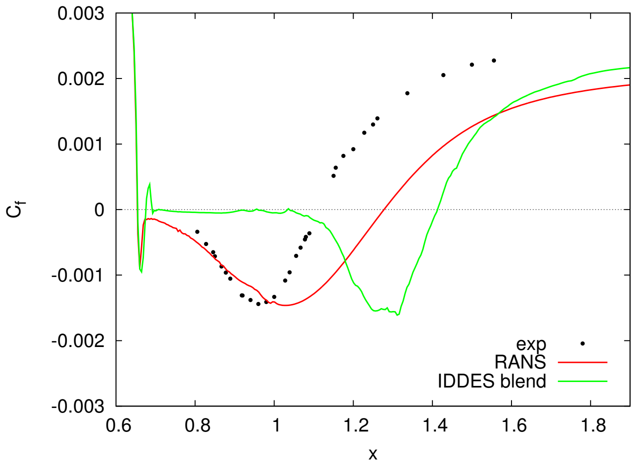

Figure 2: Space and time-averaged skin friction coefficient C_f for the 2D wall-mounted hump. The origin $x = 0$ is placed at the beginning of the hump. The scenario was experimentally examined in [7]. The stabilization-blended improved delayed DES technique predicts the recirculation length better than a simple SST RANS model but mispredicts the separation point.

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