LES quality assessment in predicting ICE flows

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Large Eddy Simulation (LES) is probably the most promising technique in computational fluid dynamics, due to his intrinsic possibility to compute directly part of the motion scales with low computational costs compared to DNS.

Anyway non linear error propagation, bad resolution on unstructured grids as the difficulty in clearly representing anisotropy at the smallest scales are the most common issues while performing a LES simulation and they become even more challenging when predicting the flow behavior on industrial applications: in fact the interactions between sources of errors behave in an unpredictable way and these coupling are strengthened by the fact that is usually difficult to work on *good build meshes* due to the complexity of the geometries analyzed.

The work proposed focuses on the correct application of the main criteria for good LES performing on a test case of industrial interest, the axisymmetric sudden expansion with valve (Ref .[1]). The flow simulated was nitrogen at a Reynolds number of 30000 with a Re_τ of 900; the high Reynolds number requires a high grid resolution to properly resolve the energetic scales of the flow and the test case looks furthermore challenging to simulate because the streaks separating from the valve are conditioned by the turbulence coherent structures present in the annular channel before the expansion.

As the problem cannot be resolved with a *good LES* without huge computational resources but still an accurate flow prediction of the inlet area is desirable, we decided to perform a preliminary simulation of the annular channel using a fine grid, and then mapping the results on the complete grid, which is obviously much coarser. To reduce the computational costs of this preliminary simulation, the annular channel flow was initialized with the utility $cylChannelPerturbU$, which is a modified version of $perturbU$ written in cylindrical coordinates. In this way in a time of 10 characteristics times we had a fully developed turbulent flow.

The initial field on the whole geometry has been set by the solution of the solver $potentialFlow$ and the the results from the annular channel simulation were mapped on the complete test case. The inflow boundary condition used was $DirectMapping$, and the mapping plane was set 2500 wall units far from the inlet. A starting simulation, called $ICE-LES-1$ was performed using a 4 million cells grid (called $base$) and the SGS model $oneEqEddy$. Furthermore other 3 simulations were performed, to test the test case sensitivity to grid refinement (simulation $ICE-LES-2$, using a 10 million cells grid called $refined$), to the application of algebraic SGS models (simulation $ICE-LES-3$, in which WALE model has been applied) and to the application of a strategy to split numerical error from SGS modeling error at the smallest scales resolved (simulation $ICE-LES-4$, in which UAD approach has been used).

The Analysis results comparing numerical and LDA data at a section 20 mm far from the valve shows that all the simulations produce quite accurate results compared to experimental data, confirming that the resolution obtained by the 2 grids is sufficient to capture the anisotropic scales which essentially drive the motion.

Having an accurate look at the results, it seems quite clear that the simulation $ICE-LES-4$ has a better prediction both of the mean velocity field and of its standard deviation,showing that the filtering approach is able to split correctly the resolved scales field from the SGS corrected field, while the simulations performed using the *oneEqEddy* SGS model looks less accurate in the results. In particular the application of the $refined$ grid doesn't produce better results, probably because the *base* grid already captures the large scales of motion necessary to correctly reproduce the flow while the $refined$ one simply exposes smaller scales to a poor resolution due to the interaction between SGS model error and numerical error.

The application of an algebraic SGS model like WALE doesn't produce better results on the prediction of the average velocity field than the simulation performed with the *oneEqEddy* SGS model, but furnishes a better prediction of the standard deviation of the velocity field.

Future development of the work include the possibility to use completely unstructured grids, which should reduce the computational costs at the risk of introduce a more unpredictable behaviour in the quality of the scales resolution.

References

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