Sixth HRLM Symposium, 26-28 September 2016, Strasbourg University, France

Session:

On scale-resolving simulation of turbulent flows using higher-accuracy quasi-1D schemes on unstructured meshes

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Currently, the scale-resolving LES and hybrid RANS-LES approaches for turbulent-flow simulation are mainly used on structured meshes and, correspondingly, exploit “structured” algorithms. Using this way, it is easier to satisfy the requirements for scale-resolving approaches which are high accuracy and minimization of numerical dissipation while maintaining the stability of the numerical scheme for the approximation of convective fluxes. At the same time, the applicable scope of LES and especially hybrid RANS-LES approaches for industrial problems while using structured meshes is limited. The use of unstructured meshes can improve the workability of these scale-resolving approaches and promote their implementation in massive industrial computations.

A common weak point of most high-accuracy “unstructured” algorithms based, in particular, on Discontinuous Galerkin or k-exact FV schemes is their high computational costs which prevents from their wide use in industry. We propose to use higher-accuracy schemes [1,2] based on quasi-1D reconstruction of variables involved to the calculation of numerical fluxes within FV approach. Thanks to the quasi-1D property, these schemes possess moderate computational expenses. An additional bonus is that, being applied to uniform grid-like meshes, they naturally transform to high-order (up to the 5th-6th) finite-difference algorithms. As a result, the “quasi-1D” schemes, still being of the second theoretical order on arbitrary unstructured mesh, provide the accuracy significantly higher than most traditional second order schemes in terms of error values. We reconstruct the variables values from both sides of the cell interface and then use them for the calculation of numerical flux with the help of Roe Riemann solver. In order to apply the algorithm for flows with strong gradients and shocks, the WENO-EBR scheme has been developed [2].

We mostly use the new recent DES formulation [3] for complex turbulent flows simulations. It has strongly advanced in solving one of the fundamental problems of the original method which is the so-called “grey area” problem resulting in the delay of “numerical” transition from the

Session:

RANS to LES solution in shear layers. According to the recent DES formulation, the acceleration of RANS-to-LES transition during the numerical simulation is gaining by the reduction both of the model and scheme dissipation at the initial region of shear layers. However the diminishing of dissipation may lead to instabilities of the solution which can be intensified by the presence of strong gradients and shocks. So, to provide the best solution on the given mesh, the numerical algorithm has to balance between diminishing the dissipation and keeping the stability of the solution during scale-resolving simulation.

To better consider both the mesh non-uniformity and the flow specifics, we develop the anisotropic numerical algorithm based on the quasi-1D schemes. In particular, it includes an adaptive switching to the WENO-EBR scheme [2] with a varying width of the approximation stencil.

The validation of the numerical algorithm and its implementation is performed on a set of canonical turbulent flows which includes the decay of isotropic homogenous turbulence, the developed turbulent flow in planar channel, and the flow in channel with backward-facing step.

The feasibility of developed and numerical algorithm is demonstrated on the predictions of two industry-oriented problems dealing with turbulent flows of different types (free and near-wall separated flows). The first problem is the simulation of subsonic free jet (Mach number M=0.9, Reynolds number $Re=1.1 \bullet 10^6$). The comparison with the experimental data is given both for the aerodynamic and far field acoustic characteristics. The second problem is the simulation of well-known case M219 which represents open-type subsonic near-cavity flow with M=0.85 and $Re=1.37 \bullet 10^6$. The numerical results are compared with the corresponding experimental and reference highly resolved LES data.

The simulation of turbulent flows and the development of higher-accuracy algorithms on unstructured meshes are performed with the support of Russian Science Foundation (Project 14-11-00060 and Russian Foundation of Basic Research (Project 15-01-07911), respectively.

References

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