p-adaptive LES of transitional flows using discontinuous Galerkin methods

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ABSTRACT

Accurate simulation of turbulent flows with complex unsteady features, such as massive separation, remains beyond the current capabilities of industrial CFD methods. A major challenge in simulating turbulent flows with large-scale unsteady features is the invalidity of the common physical assumptions made in RANS-type approaches. This requires resolving the turbulence at a reasonable level of accuracy through large eddy simulation (LES) implying considerably higher computational cost. Given the limitations of computational power, performing such simulations at the industrial scale requires using efficient and scalable numerical methods with geometrical flexibility, like the high-order accurate discontinuous Galerkin (DG) method. One of the most interesting properties of the DG method is the possibility of locally adapting the spatial resolution by either reducing the mesh size (h-adaptation) or by locally increasing the degree of the polynomial approximation (p-adaptation). This feature is of interest for the development of adaptive algorithms to be used in scale-resolving simulations of turbulence on complex geometries. Adaptive simulations, however, require the use of error estimation strategies which must be specifically tailored for turbulent flow simulations on irregular meshes.

In this work we present a statically adaptive p-adaptive algorithm for the simulation of turbulent flows. Based on our previous research [1] a new refinement indicator has been developed based on an estimate of the H_1-norm of the error of the instantaneous momentum field. The proposed error estimate can be implemented as a simple post-processing operation requiring only knowledge of the instantaneous solution within an element and its immediate neighbours. Thanks to the dependence of this new estimate on the gradient vector components, it can also provide information on the anisotopy of the error. This feature can be most useful in the development of hp-adaptation strategies. The p-adaptive algorithm used in this research therefore allows for the refinement and coarsening of the local polynomial degree as a function of the maximum over time of the error measure. The computational gain provided by the adaptive algorithm is studied by performing p-adaptive LES simulations of the flow past a NACA0012 airfoil at Reynolds number $\mathrm{Re} = 50,000$ and incidence angle $\alpha = 5°$ [2]. This configuration is characterized by the presence of a laminar recirculation bubble, a complex transition mechanism leading to a fully three-dimensional reattachment and a turbulent wake. The analysis of this configuration illustrates the efficiency of the developed algorithm for scale-resolving simulations of flows of industrial interest.

REFERENCES

[1] F. Naddei, M. de la Llave Plata, V. Couaillier, F. Coquel, *"A comparison of refinement indicators for p-adaptive simulations of steady and unsteady flows using discontinuous Galerkin methods"*, Journal of Computational Physics, 376, 2019, pp. 508-533.

[2] O. Lehmkuhl et al., *"On the large-eddy simulations for the flow around aerodynamic profiles using unstructured grids"*. Computers & Fluids 84, 2013, pp. 176-189.