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ADAPTIVE FINITE ELEMENT METHODS FOR TURBULENT FLOWS

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In the context of an ever-increasing availability of computing power, the development of robust methods for the Large Eddy Simulation (LES) of turbulent flows in complex geometries remains a key challenge for engineering applications in CFD such as aerodynamics or ocean and atmosphere modelling. As resolution of all turbulent scales is by definition not possible, only largest scales in flows are represented while a subgrid viscosity is usually constructed to take into account of the energy of the small vorticial structures. Such methods, like Reynolds-Averaged Navier–Stokes turbulent models, have been historically chosen for their computing efficiency, with the compromise of requiring (possibly non-trivial) *ad hoc* physical modelling.

Another approach, sometimes coined Implicit LES, consists in seeing the turbulence model as a by-product of the discretization of the partial differential equation. As the subgrid model represents then a computable modelling error, a residual-based turbulence modelling with *a posteriori* error control seems a natural option. While the reference method [6] relies on an equal order Lagrange finite element discretization of the Navier–Stokes equation stabilized by a Streamline-Diffusion term, other approaches developed in the past few years with the intention to provide a mathematical framework to LES, such as entropy viscosity type regularizations [7], are also considered.

Moreover, the adaptive strategy developed in [5], involves using the solution of an approximate adjoint problem to obtain *a posteriori* estimates of the error for a chosen output functional of the solution. Due to the semi-linearity of the momentum equation, the dual problem is linearized around the computed primal solution. The stability of the adjoint problem acts as a weight for local residual errors in the a posteriori error estimates. For certain problems, blow-up in the adjoint solution has been reported [1, 8], which opens to further questions.

The current pace of development of computing architectures, while permitting the move to more sophisticated numerical algorithm renders writing massively parallel adaptive finite element solvers inevitable [3]: one can basically compute more and faster that one can post-process the results. The substantial work to provide UNICORN with a scalable implementation [4] proved efficient and robust in different applications [2]. Thus, an effort in solver development and verification methodology to ensure reproducibility of the numerical experiments and computation/post-processing of quantities of interest at runtime for uncertainty quantification of data and models is now the natural continuation.

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