NUMERICAL TOOLS FOR THE SIMULATION OF TURBULENT FLOWS AROUND A REENTRY CAPSULE

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In Direct Numerical Simulations (DNS) of turbulent flows, one attempts to fully resolve all turbulence length scales and frequencies in the flow, by solving the unsteady Navier-Stokes equations on a highly refined mesh over a considerable number of small time steps. In Large Eddy Simulations (LES), only the large turbulence length scales are fully resolved whereas smaller ones are accounted for using a subgrid scale model. Computations of flows at higher Reynolds numbers are allowed with LES but the requirements in terms of meshes and time steps remain considerable. Such simulations can be accomplished only by using state-of-the-art numerical methods and supercomputing facilities.
For that purpose, a new library called FlexMG has been first developed and allows to use various types of iterative solvers preconditioned by algebraic multigrid methods. Two families of algebraic multigrid preconditioners have been implemented, of smooth aggregation-type and non nested finite-element-type. Unlike pure gridless multigrid, both of these families use the information contained in the initial fine mesh. A hierarchy of coarse meshes is also needed for the non nested finite-element-type multigrid so that our approaches can be considered as hybrid. Our aggregation-type multigrid is smoothed with either a constant or a linear least square fitting function while the non nested finite-element-type multigrid is already smooth by construction. All these multigrid preconditioners are tested as stand-alone solvers or coupled to a GMRES method. After analyzing the accuracy of the solutions obtained with our solvers on a typical test case in fluid mechanics, their performance in terms of convergence rate, computational speed and memory consumption is compared with the performance of a direct sparse LU solver as a reference. Finally, the importance of using smooth interpolation operators is also underlined in the work.
The second part of this work is devoted to the study of LES models. A constant-coefficient-based Smagorinsky and WALE model for the large eddy simulation of turbulent flows are considered under different formulations. This includes a classical version of both the Smagorinsky and WALE models and several scale-separation formulations where the resolved velocity field is filtered in order to separate the small turbulent scales from the large ones. From this separation of turbulent scales, the strain rate tensor and/or the eddy viscosity of the subgrid stress tensor is computed from the small scales only. Finally, two variational multiscale (VM) methods are also analyzed. In addition to the eddy viscosity and strain rate tensor based on the small scales, the VM method implies the projection of weight functions in a subspace related to the small scales. Finally, the relevance of our models is assessed with the large eddy simulation of a fully developed turbulent channel flow at two Reynolds number under statistical equilibrium. In addition to the analysis of the mean eddy viscosity computed for all our LES models, comparisons in terms of shear stress, root mean square velocity and mean velocity are performed with a fully resolved direct numerical simulation as a reference.
The final objective of this work is to put together the numerical tools mentioned above in order to study the turbulent flow around a fixed Apollo capsule. At low speed, before the splashdown, the turbulent flow field induces unsteady forces around an entry capsule. In particular, even if the capsule geometry is axisymmetric, the flow field is not axisymmetric. The understanding of these phenomena is essential to ensure both static and dynamic stability. The aim of the present study is to analyze numerically the flow field around an entry capsule at low and moderate Reynolds numbers, using SFELES. The results obtained are compared qualitatively with experiments at low speed and quantitatively with literature data at higher Reynolds numbers.

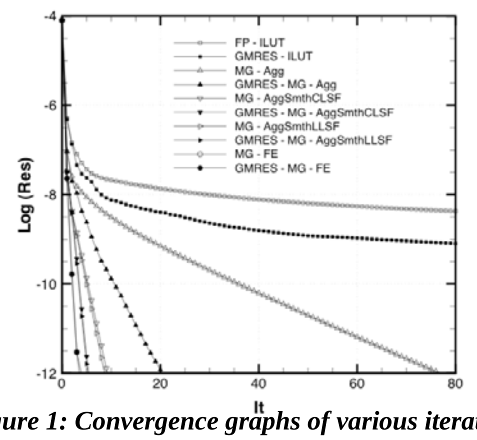

Figure 1: Convergence graphs of various iterative methods from FlexMG coupled with SFELES on a typical time step

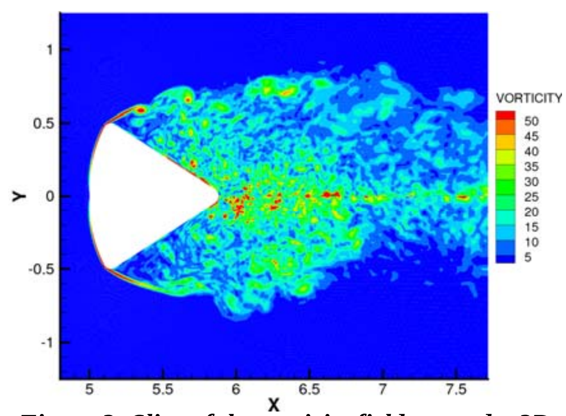

Figure 2: Slice of the vorticity field around a 3D Apollo capsule at Re = 10000, using SFELES and the classical Smagorinski model