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THE VARIATIONAL MULTISCALE-MULTIGRID METHOD (VM^3) FOR LARGE EDDY SIMULATION OF TURBULENT FLOWS

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ABSTRACT

The Variational Multiscale-Multigrid Method (VM^3) is introduced in [1]. It aims at bringing closer together two numerical approaches having acted independently so far, the variational multiscale method (VMM) and multigrid solvers. On the one hand, the VMM (see, e.g., [2]) represents a framework within which methods may be developed for problems with broad scale ranges, which often pose an unsolvable challenge for standard numerical methods. On the other hand, multigrid solvers are currently the only known solvers that scale O(N) and therefore appear to be the most promising approach to efficiently solve large-scale problems. The VM^3 relies on aggregation-based algebraic multigrid (AMG) as proposed, e.g., in [3] and [4], employing the respective aggregation procedures for the scale separation. The VM^3 in the form of a standard stabilized method with the addition of a discontinuity-capturing term only to the finer of the resolved scales was successfully applied to strongly convection-dominated convection-diffusion problems. A substantial reduction of the oscillations still remaining at sharp layers when applying only a standard stabilized method can be achieved with the VM^3. This reduction is obtained without any noticable smearing, which usually results from the addition of a "full-scale" standard discontinuity-capturing term.

The basic idea of restricting modeling terms to the finer resolved scales, which the framework of the VM^3 conveniently enables, was introduced in the context of large-eddy simulation (LES) of turbulent flows in [5] and has been successfully applied to several turbulent flow problems in the meantime, see, e.g., [6] for a review. Among others, a multigrid-based procedure was introduced and succesfully applied in [7]. For that procedure, it was necessary to generate two grids, a coarser "parent" grid identifying the coarser of the resolved scales and a finer "child" grid defining the complete resolution limit. Those two grids had to be kept throughout the computation. In contrast to that, by reverting to

aggregation-based AMG procedures, no grid other than the basic grid has to be generated, since AMG methods act completely free from any further geometrical grid specifications. Efficient implementation strategies, which are mandatory for large-scale turbulent flow simulations, will be addressed in this talk. Via a Fourier analysis on a simplified model problem, we can show that a projective multigrid-based scale separation as we employ when using a VM^3 based on plain aggregation leads to a strict confinement of the dissipative modeling effect to the finer of the resolved scales.

Besides the "classical" variational multiscale approach to LES described above, a residual-based variational multiscale approach to LES was introduced, see, e.g., [8]. Results obtained from applications of the VM3 will be compared to results obtained with the residual-based method as well as with traditional LES modeling approaches for wall-bounded turbulent flow examples such as the turbulent channel flow. At the end of this talk, new ways towards a potential combination of the classical and the residual-based variational multiscale LES exploiting their respective advantages will be outlined.

REFERENCES

[1] V. Gravemeier, M. W. Gee and W. A. Wall. "The variational multiscale-multigrid method (VM^3): bringing method and solver closer together". Preprint, to be submitted for publication in *Comput. Methods Appl. Mech. Engrg.*, 2008.

[2] T.J.R. Hughes, G.R. Feijoo, L. Mazzei and J.-B. Quincy. "The variational multiscale method - a paradigm for computational mechanics". *Comput. Methods Appl. Mech. Engrg.*, Vol. **166**, 3–24, 1998.

[3] P. Vanek, J. Mandel and M. Brezina. "Algebraic multigrid based on smoothed aggregation for second and fourth order problems". *Computing*, Vol. **56**, 179–196, 1996.

[4] R. Tuminaro and C. Tong. "Parallel smoothed aggregation multigrid: aggregation strategies on massively parallel machines". In: J. Donnelley (ed.), Super Computing 2000 Proceedings, 2000.

[5] T.J.R. Hughes, L. Mazzei and K.E. Jansen. "Large eddy simulation and the variational multiscale method". *Comput. Visual. Sci.*, Vol. **3**, 47–59, 2000.

[6] V. Gravemeier. "The variational multiscale method for laminar and turbulent flow". *Arch. Comput. Meth. Engng.*, Vol. **13**, 249–324, 2006.

[7] V. Gravemeier. "Scale-separating operators for variational multiscale large eddy simulation of turbulent flows". *J. Comput. Phys.*, Vol. **212**, 400–435, 2006.

[8] Y. Bazilevs, V.M. Calo, J.A. Cottrell, T.J.R. Hughes, A. Reali and G. Scovazzi. "Variational multiscale residual-based turbulence modeling for large eddy simulation of incompressible flows". *Comput. Methods Appl. Mech. Engrg.*, Vol. **197**, 173–201, 2007.