11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

AN EXTENDED ALGEBRAIC VARIATIONAL MULTISCALE-MULTIGRID-MULTIFRACTAL METHOD (XAVM^4) FOR LARGE-EDDY SIMULATION OF TURBULENT TWO-PHASE FLOW

Volker Gravemeier[1,2,*], Ursula Rasthofer[1] and Wolfgang A. Wall[1,2]

[1] Institute for Computational Mechanics, Technische Universität München, Boltzmannstr. 15, 85748 Garching, Germany, vgravem@lnm.mw.tum.de, www.lnm.mw.tum.de
[2] AdCo Engineering^{GW} GmbH, Lichtenbergstr. 8, 85748 Garching, Germany, gravemeier@adco-engineering-gw.com, www.adco-engineering-gw.de

Key words: *Turbulent two-phase flow, Large-eddy simulation, Multifractal subgrid-scale modeling, Variational multiscale method, Extended finite element method, Nitsche's method.*

Turbulent two-phase flows are encountered in various industrial applications and natural phenomena. From a computational point of view, turbulent two-phase flows exhibit several particularly demanding challenges such as an adequate representation of the interface between the phases including the incorporation of the corresponding coupling conditions as well as an appropriate approach for turbulence. In this presentation, a novel computational method particularly focusing on the aforementioned issues is proposed for large-eddy simulation of turbulent two-phase flow.

Fixed-grid approaches based on the extended finite element method, which enables the representation of discontinuities in the solution fields by enlarged function spaces, provide a promising framework for numerically simulating complex two-phase flows; see, e.g., [1]. Here, the evolution of the moving interface between the phases is governed by a level-set method, allowing for arbitrary interface deformations. Using Nitsche's method, the continuity of the velocity field across the interface is imposed weakly within the extended finite element method. In particular, face-oriented ghost-penalty terms are imposed on elements intersected by the interface to deal with any cut situation; see, e.g., [2]. Extensions of Nitsche's method in the form of convective flux terms are additionally included to cope with convection-dominated turbulent flows.

In large-eddy simulation of turbulent flow, only the larger flow structures are resolved, while the smaller flow structures, which exhibit a more universal character, are modeled. The multifractal subgrid-scale modeling approach, originally proposed for LES of turbulent incompressible flow in [3], allows for directly closing the nonlinear subgrid-scale terms arising in the variational multiscale formulation of the incompressible Navier-Stokes equations, as shown in [4]. Based on the driving mechanism of turbulent flow, the subgrid-scale vorticity is first reconstructed by a two-step multifractal process and then inserted into the law of Biot-Savart to calculate the subgrid-scale velocity. The multifractal procedure to approximate the subgrid-scale vorticity consists of a multiplicative cascade to recover its magnitude from the subgrid-scale enstrophy and a decorrelation cascade to determine its orientation. Level-transfer operators from plain aggregation algebraic multigrid methods are applied to further decompose the resolved scales into larger and smaller ones within the multifractal reconstruction process; see also, e.g., [5].

In this talk, the eXtended Algebraic Variational Multiscale-Multigrid-Multifractal Method (XAVM^4), combining a Nitsche-type extended variational multiscale method for two-phase flow and the multifractal subgrid-scale modeling approach for large-eddy simulation of turbulent incompressible flow, will be derived. To illustrate the potential of the proposed method, results from two numerical examples will be presented. The first example will be selected from various configurations of turbulent bubbly channel flows as considered, e.g., in [6]. A two-phase flow past a backward-facing step will be shown as the second numerical example; see, e.g., [7].

REFERENCES

[1] U. Rasthofer, F. Henke, W.A. Wall and V. Gravemeier. An extended residual-based variational multiscale method for two-phase flow including surface tension. *Comput. Methods Appl. Mech. Engrg.*, Vol. **200**, 1866–1876, 2011.

[2] E. Burman and P. Hansbo. Fictitious domain methods using cut elements: III. A stabilized Nitsche method for Stokes' problem. *JTH Research Report 2011:06, Jönköping University*, pp. 1–19.

[3] G.C. Burton and W.J.A. Dahm. Multifractal subgrid-scale modeling for large-eddy simulation. I. Model development and a priori testing. *Phys. Fluids*, Vol. **17**, 075111-1–075111-16, 2005.

[4] U. Rasthofer and V. Gravemeier. Multifractal subgrid-scale modeling within a variational multiscale method for large-eddy simulation of turbulent flow. *J. Comput. Phys.*, Vol. **234**, 79–107, 2013.

[5] V. Gravemeier, M.W. Gee and W.A. Wall. An algebraic variational multiscale-multigrid method based on plain aggregation for convection-diffusion problems. *Comput. Methods Appl. Mech. Engrg.*, Vol. **198**, 3821–3835, 2009.

[6] I.A. Bolotnov, K.E. Jansen, D.A. Drew, A.A. Oberai, R.T. Lahey Jr. and M.Z. Podowski. Detached direct numerical simulations of turbulent two-phase bubbly channel flow. *Int. J. Multiphase Flow*, Vol. **37**, 647–659, 2011.

[7] D. Kim and P. Moin. Direct numerical study of air layer drag reduction phenomenon over a backward-facing step. *Annual Research Briefs 2010, Center for Turbulence Research*, pp. 351–363.