COUPLING FIELDS AND SCALES IN COMPUTATIONAL (BIO) FLUID DYNAMICS – ADVANCED METHODS AND APPLICATIONS

Wolfgang A.Wall,
Georg Bauer, Peter Gamnitzer, MichaelW. Gee, Axel Gerstenberger, Volker Gravemeier,
Ulrich Küttler, Ursula M. Mayer, Alexander Popp, Lena Wiechert

Institute for Computational Mechanics, Technische Universit¨at M¨unchen
Boltzmannstr. 15, 85748 Garching b. M¨unchen, Germany
e-mail: wall@lnm.mw.tum.de

ABSTRACT

Many contemporary problems in engineering and the applied sciences cannot be solved or adequately analyzed by just looking at one (physical) field or at one (spatial and/or temporal) scale. These facts motivated huge research efforts in recent years, since a variety of robust modeling and simulation approaches are needed to tackle such coupled field problems (often also called multifield or multiphysics problems) as well as multiscale problems. And in many of these problem classes the flow field and flow solver, respectively, manifest as essential parts of the problem as well as of the modeling and simulation approaches.

Many of the approaches we are presenting are not tied to any specific flow solver. Nevertheless the lecture will start with a brief presentation of our CFD approach. In this approach the large spectrum of scales already present in many pure flow problems is tackled through a Variational Multiscale approach and transfer between scales is realized with algebraic multilevel strategies. This AVM-approach has been successfully applied to all different flow regimes – from laminar to transitional and turbulent – and both to incompressible as well as to low Mach number flows.

In recent years our own research activities covered quite a lot of different multifield and multiscale problems coming from very different applications areas. Among others they range from fluid-structure interaction to electrochemical, two-phase and combustion problems and cover application areas from Aerospace to Bioengineering and Biophysics. A brief overview will both demonstrate involved fields and scales as well as solution strategies in these problem classes. Usually all these problems are becoming very big and hence efficiency is a crucial aspect, besides adequate modeling and accurate and robust methods.

From the above spectrum of problem classes fluid-structure interaction (FSI) will be selected for a more detailed presentation. Besides more classical ALE type of approaches we will show advantages of a recently proposed fixed-grid approach in some important scenarios. Independent of the specific formulation, efficient and robust solution strategies are essential for enabling treatment of complex applications and we will demonstrate superior performance of a recently proposed AMG based solver. We will also look into different scales in FSI, e.g. scales where intermolecular and surface potentials are important aspects that need to be covered. In some cases contacting submerged bodies need to be described and we will show a novel fluid-structure-contact interaction approach. Special care also has to be taken when the flows in FSI scenarios are turbulent. All methods will be described and their performance will be demonstrated along with applications from different fields. Some especially challenging applications from computational bioengineering will be included – some of those even asking for specific formulations like volume coupling FSI.

REFERENCES

[1] V. Gravemeier, M.W. Gee, M. Kronbichler, W.A. Wall, An Algebraic Variational Multiscale-Multigrid Method for Large Eddy Simulation of Turbulent Flow, *Comp. Meth. in Appl. Mech. And Engng.*, 199:853–864, 2009.

[2] V. Gravemeier, W.A. Wall, Residual-based variational multiscale methods for laminar, transitional and turbulent variable-density flow at low Mach number, *Int. J. Numer. Methods Fluids*, accepted 2009.

[3] G. Bauer, V. Gravemeier, W.A. Wall, A 3D finite element approach for the coupled numerical simulation of electrochemical systems and fluid flow, *Int. J. Numer. Meth. Biomed. Eng.*, submitted, 2009.

[4] A. Gerstenberger, W.A. Wall, An eXtended Finite Element Method/Lagrange multiplier based approach for fluid-structure interaction. *Comp. Meth. in Appl. Mech. and Engng.*, 197:1699–1714, 2008.

[5] A. Gerstenberger, W.A. Wall, Enhancement of fixed-grid methods towards complex fluid-structure interaction applications, *Int. J. Numer. Meth. Fl.*, Vol.57(9), pp.1227–1248, 2008.

[6] A. Gerstenberger, W.A. Wall, An embedded Dirichlet formulation for 3D continua, *Int. J. Numer. Meth. Eng.*, published online, DOI: 10.1002/nme.2755, 2009.

[7] M.W. Gee, U. Küttler, W.A. Wall, Truly monolithic algebraic multigrid for fluid-structure interaction. *Int. J. Numer. Meth. Eng.*, accepted, 2010.

[8] U. Küttler, M.W. Gee, Ch. Förster, A. Comerford, W.A. Wall, Coupling strategies for biomedical fluid-structure interaction problems. *Int. J. Numer. Meth. Biomed. Eng.*, 26:305–321, 2010.

[9] U. Küttler, W.A. Wall, Strong coupling schemes for fluid-structure interaction. *Comp. Meth. In Appl. Mech. and Engng.*, submitted, 2010.

[10] U.M. Mayer, A. Popp, A. Gerstenberger, W.A. Wall, 3D fluid-structure-contact interaction based on a combined XFEM FSI and dual mortar contact approach. *Comp. Mech.*, 46(1):53–67, 2010.

[11] U.M. Mayer, W.A. Wall, A finite element approach to 3D intermolecular and surface interaction of multiple flexible mesoscopic structues in fluid flow, in preparation, 2010.

[12] W.A. Wall, P. Gamnitzer, A. Gerstenberger, Fluid-structure interaction approaches on fixed grids based on two different domain decomposition ideas. *Int. J. Comput. Fluid. Dyn.*, 22(6):411–427, 2008.

[13] L. Wiechert, W.A. Wall, Fluid-structure interaction including volume coupling of homogenized subdomains for treating artificial boundaries, in preparation, 2010.

[14] W.A.Wall, L.Wiechert, A. Comerford, S. Rausch, Towards a comprehensive computational model for the respiratory system, *Int. J. Numer. Meth. Biomed. Eng.*, accepted, 2010.