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Variational Multiscale Methods in Computational Fluid Dynamics: Recent Progress and Challenges with Emphasis on the Development of Turbulence Models

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Abstract:
I will discuss the development of the variational multiscale (VMS) approach for solving partial differential equation systems arising in fluid dynamics. The background is this: Any reasonable method utilizing functions capable of resolving the exact solution will obtain it. However, in numerical analysis we typically employ finite-dimensional spaces of functions that are unable to give good approximations for many fluid dynamical problems of practical interest. In addition, the basic variational methods (e.g., Galerkin) are not as reasonable as often assumed in the finite-dimensional setting. Stability, present in the continuous setting, is often not inherited for typically utilized finite-dimensional subspaces. The possibilities are to improve the function spaces, improve the variational methods, or both. Improving the spaces is possible but difficult. It has been a pathway to attaining stability for simpler problems. For more complex problems, enhancing the stability of the variational method, without upsetting its consistency, has been a more practical direction. This is the essence of so-called stabilized methods. But stability is not the only issue in computational fluid dynamics (CFD). In modeling turbulence, the effects of unresolved scales on resolved scales must also be accounted for. VMS is a paradigm that derives directly from the variational formulation of the partial differential equations. In very simple situations it coincides with stabilized methods, but in more complicated cases it is richer. In addition to providing additional stability, it accounts for the effects of unresolved scales, and thus is a general framework for turbulence modeling as well as the derivation of CFD methods. Recent research in VMS concerns comparisons with stabilized methods, calculation of the fine-scale Greenâ��s function, the use of continuous and discontinuous function spaces, minimizing the error in various measures, approximating discontinuities, the fine-scale field as error estimator, geometrically inspired approximations, weak boundary conditions, and turbulence modeling. In my talk I will sample from some of these recent developments and emphasize the use of VMS as a theoretical means for developing turbulence models. In particular, I will present a formulation of LES that is derived entirely from the Navier-Stokes equations without recourse to any external ad hoc devices, such as eddy viscosity models, and I will demonstrate the effectiveness of the ideas through numerical examples.

Speaker's Bio:
Dr. Hughes holds B.E. and M.E. degrees in Mechanical Engineering from Pratt Institute and an M.S. in Mathematics and Ph.D. in Engineering Science from the University of California at Berkeley. He began his career as a mechanical design engineer at Grumman Aerospace, subsequently joining General Dynamics as a research and development engineer. Upon receiving his Ph.D. at Berkeley, he received the Bernard Friedman Prize in Applied Mathematics, and thereafter taught at Berkeley eventually moving to California Institute of Technology and then Stanford University before joining the University of Texas at Austin. At Stanford he served as Chairman of the Division of Applied Mechanics, Chairman of the Department of Mechanical Engineering, Chairman of the Division of Mechanics and Computation, and occupied the Mary and Gordon Crary Family Chair of Engineering. At the University of Texas at Austin, he is Professor of Aerospace Engineering and Engineering Mechanics and occupies the Computational and Applied Mathematics Chair III. He is a Fellow of the American Academy of Mechanics, the American Society of Mechanical Engineers (ASME), the American Institute of Aeronautics and Astronautics, the American Society of Civil Engineering (ASCE), and the American Association for the Advancement of Science, co-editor of the international journal Computer Methods in Applied Mechanics and Engineering, a Founder, Fellow and past President of the U.S. Association for Computational Mechanics (USACM), a Founder, Fellow and past President of the International Association for Computational Mechanics (IACM), a past Chairman of the Applied Mechanics Division of ASME, and is licensed to practice as a Professional Engineer in the state of Texas. Dr. Hughes has been a leading figure in the development of the field of computational mechanics. He has published over 300 works on computational methods in solid, structural and fluid mechanics and he is one of the most widely cited authors in the field. Dr. Hughes was identified by ISI as among the 15 most highly cited authors in Computer Science and the original 100 most highly cited authors in Engineering (all fields). His research has included many pioneering studies of basic theory as well as diverse applications to practical problems. He received the Walter L. Huber Civil Engineering Research Prize in 1978 from ASCE, the Melville Medal in 1979 from ASME, and the 1993 Computational Mechanics Award of the Japan Society of Mechanical Engineers. In 1995 Dr. Hughes was elected to membership in the National Academy of Engineering. In 1997 he was awarded the Von Neumann Medal, the highest award of USACM, and in 1998 he received the Gauss-Newton Medal, the highest award of IACM, and was named the recipient of the Worcester Reed Warner Medal from ASME. He was the first engineer to occupy the Cattedra Galileiana (Galileo Galilei Chair), Scuola Normale Superiore, Pisa, in 1999, and he held the Eshbach Professorship, Northwestern University, in 2000. In 2003, Dr. Hughes received a Doctorat honoris causa from the Universite catholique de Louvain, Belgium. His seminal studies on contact-impact, plate and shell elements, time integration procedures, incompressible media, algorithms for inelastic materials, nonlinear solution strategies, iterative equation solvers, parallel computing, and finite elements for fluids have had a major impact on the development of software used throughout the world today. His most recent work includes the determination of hydrodynamic noise sources in turbulent flows, simulation based medical planning for cardiovascular disease and predictive surgery, study and application of Large-Eddy Simulations (LES) in turbulence, multiscale methods in science and engineering, and Isogeometric Analysis: geometrically exact methods in computational mechanics.

Refreshments will be served.
This lecture has a reception.

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