56th Annual Technical Meeting of the Society of Engineering Science (SES2019)
October 13 - 15, 2019, Washington University, St. Louis, MO, U.S.A.

A New Class of Variational Multiscale Methods for Fluid Mechanics

Arif Masud
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign (amasud@illinois.edu)

This talk presents a new class of Variational Multiscale Methods with enhanced stability and accuracy properties for problems with dominant interfacial phenomena, embedded constraints, and weak or strong discontinuities. A multiscale decomposition of the velocity and pressure fields into coarse- and fine-scales leads to two coupled systems that describe physics at the global and the local levels, respectively. The fine scale system facilitates various modeling options that are systematically exploited to variationally derive (i) techniques for consistent coupling of multiple interacting PDEs that govern flow physics on adjoining subdomains such as Stokes-Darcy flows, (ii) develop methods for modeling interfacial physics in discrete multiphase flows and in free-surface flows, and (iii) to derive residual-based closure models for turbulence. Variational multiscale ideas are extended to non-Newtonian fluids and a stabilized mixed method is developed that optimally enforces internal constraints that are dictated by the viscoelastic constitutive equations. A shear-rate version of these equations is coupled with a viscoelastic artery model to highlight the significance of non-Newtonian effects in the coupled response of blood-artery system in biofluid dynamics. Several examples are presented to highlight the generality of the proposed methods and their application to problems of contemporary interest in science and engineering.

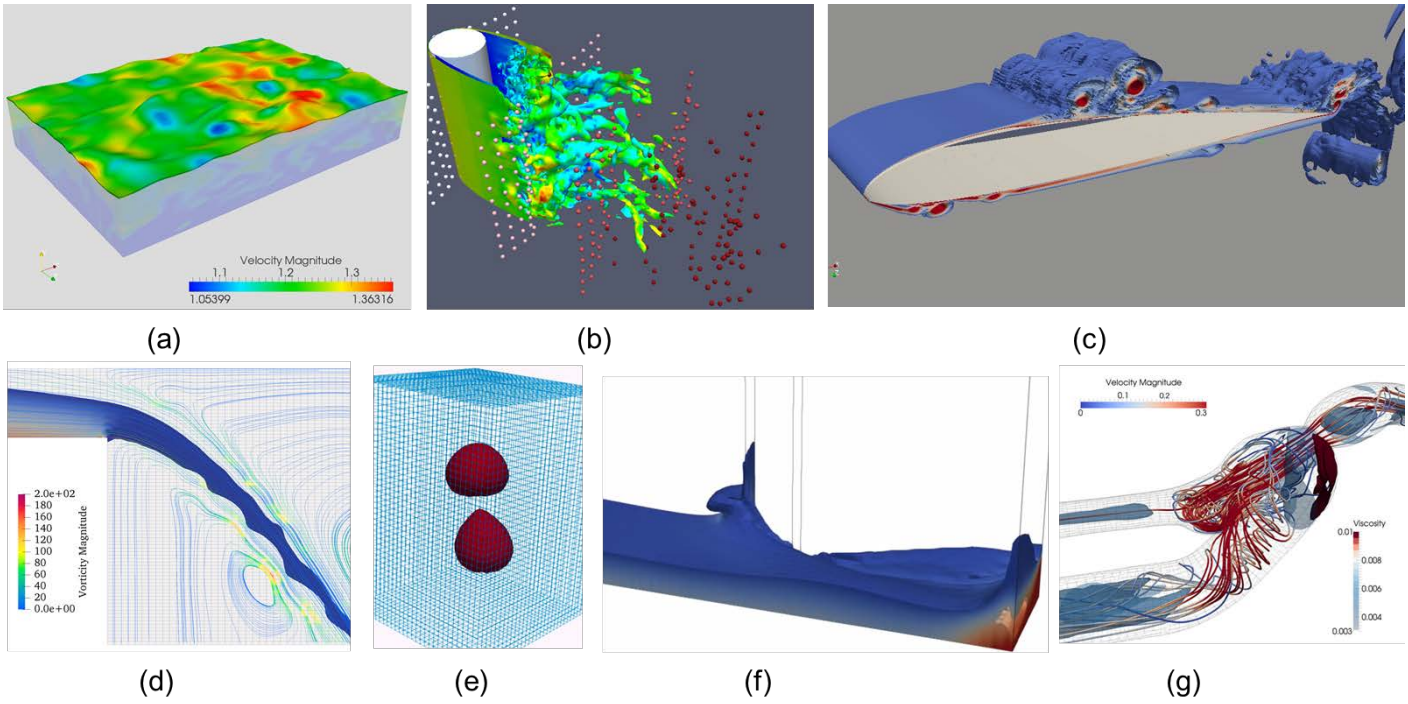

Figure 1. Classes of flow mechanics problems: (a) free surface flows, (b) turbulent flows around submerged structures, (c) turbulent flow around an oscillating air-foil, (d) surface instabilities in free falling water columns, (e) discrete multiphase bubble flow, (f) surface flows and breaking waves, and (g) non-Newtonian flows and blood-artery interaction.

References

[1] A. Masud and T. J. R. Hughes, A stabilized mixed finite element method for Darcy flow. Computer Methods in Applied Mechanics and Engineering, vol. 191, 4341-4370, 2002.

[2] A. Masud and R. Khurram, A multiscale finite element method for the incompressible Navier-Stokes equations. Computer Methods in Applied Mechanics and Engineering, vol. 195, 1750-1777, 2006.

[3] A. Masud and R. Calderer, A variational multiscale method for incompressible turbulent flows: Bubble functions and fine scale fields. Computer Methods in Applied Mechanics and Engineering, vol. 200, 2577-2593, 2011.

[4] J. Kwack, A. Masud and K.R. Rajagopal, "Stabilized mixed three-field formulation for a generalized incompressible Oldroyd-B model", International Journal for Numerical Methods in Fluids, 83:704–734, 2017.