Industrial Fluid Mechanics
Mécanique des fluides industrielle
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BRUNO DESPRES, CEA
Cell-centered Lagrangian schemes

The computation of compressible flows for plasma physics in any dimension requires reliable, robust and accurate schemes. We shall describe some recent progresses that have been made in the case of cell-centered schemes.

These methods are by construction compatible with ALE (Arbitrary Lagrange Euler) techniques. It makes them a good alternative for the computation of multi-materials problems which are part of many industrial flows. Most of these results have been obtained with colleagues at the CEA.

MIGUEL FERNANDEZ, INRIA

IAN FRIGAARD, UBC
Visco-plastic fluid displacements in horizontal narrow eccentric annuli: stratification and traveling wave solutions

We consider laminar displacement flows in narrow eccentric annuli, oriented horizontally, between 2 fluids of Herschel–Bulkley type, (*i.e.*, including Newtonian, power law and Bingham models). This situation is modeled via a Hele–Shaw approach. Whereas slumping and stratification would be expected in the absence of any imposed flow rate, for a displacement flow we show that there are often steady state traveling wave solutions in this displacement. Surprisingly these may exist even at large eccentricities and for large density differences between the fluids. When heavy fluids displace light fluids, annular eccentricity opposes buoyancy and steady states are more prevalent than when light fluids displace heavy fluids. For large ratios of buoyancy forces to viscous forces we derive a lubrication-style displacement model. This simplification allows us to find necessary and sufficient conditions under which a displacement can be steady, which can be expressed conveniently in terms of a consistency ratio. It is interesting that buoyancy does not appear in the critical conditions for a horizontal well. Instead a competition between fluid rheologies and eccentricity is the determining factor. Buoyancy acts only to determine the axial length of the steady state profile.

This is joint work with M. Carrasco-Teja, B. Seymour and S. Storey.

JEAN-FRÉDÉRIC GERBEAU, INRIA Paris–Rocquencourt
Generalized Navier Boundary Conditions for ALE two-fluid simulations

We are interested in the numerical simulation of two incompressible viscous fluids separated by a free interface. We use an Arbitrary Lagrange Euler (ALE) formulation of the problem. The purpose of the talk is to address various numerical issues, in particular some stability and conservation properties. The role of the Geometric Conservation Law (GCL) will be discussed. We will introduce a notion of "Surface Conservation Law" which may be helpful to analyse the numerical scheme when the surface tension is taken into account. A difficult problem in the modelling of two-fluid flows in a bounded domain concerns the displacement of the contact line, namely the points which are at the intersection of the boundary of the domain and the interface separating the two fluids. We will show that variational formulations are well-suited to the "Generalized Navier Boundary Conditions" introduced by Qian, Wang and Sheng. Owing to these boundary conditions, it is possible to circumvent the incompatibility between the classical no-slip boundary condition and the fact that the contact line of the interface on the wall is actually moving. We will present numerical experiments on two-fluid flows in narrow channels and we will compare these results with molecular dynamics simulations from the literature.

This is a joint work with T. Lelièvre.

SERGUEI IAKOVLEV, Dalhousie University, Halifax, Canada
Cavitation in shock-subjected shell systems

Cavitation induced as a result of the interaction between shock waves and thin-walled structures submerged into and/or filled with fluid is an important factor that needs to be taken into account when the shock response of industrial systems is analyzed. When shock-induced cavitation takes place, it is known to dramatically change the dynamics of the process, often leading to a very significant increase in the overall loading experienced by the structure. Cavitation in general is a difficult phenomenon to model, and it becomes particularly challenging when coupled with the structural dynamics. In this presentation an approach based on a linear model of the interaction is used to predict the most probable regions where cavitation is expected to develop inside and outside the shell. It is demonstrated that, depending on the circumstances, several different cavitation scenarios can exist for the same system, especially when the internal fluid volumes are present. Each scenario has different consequences in terms of both the overall dynamics of the system and the potential damage to the structure.

This is a joint work with Bryan MacDonald, Jonathan Gaudet, and Garrett Dooley.

DONG LIANG, York University
Energy-Conserved S-FDTD Schemes in Computational Electromagnetics

Computational electromagnetics has been playing a more and more important role in the electromagnetic industry. Numerical modeling has emerged recently as a crucial enabling technology for many areas of application in the modern society, such as radio-frequency, microwave, integrated optical circuits, antennas, and wireless engineering. It is of special importance to develop efficient numerical methods for effective and accurately simulating propagation of electric and magnetic waves in large scale field and long time duration. On the other aspect, in lossless medium, it is well known that the density of the electromagnetic energy of the wave is constant at different times. Thus, keeping physically this invariance in time is a greatly important issue in constructing efficient numerical schemes for computing propagation of electromagnetic waves. However, most previous ADI or splitting schemes break this property of energy conservation. In this study, we develop energy-conserved splitting finite-difference time-domain schemes for electromagnetic computation. Both theoretical analysis and numerical experiment are taken to show the efficiency of the new schemes.

This is joint work with W. Chen and X. Li.

YVON MADAY, Paris VI

BERTRAND MAURY, Paris-Sud

PETER MINEV, University of Alberta, Department of Mathematical and Statistical Sciences
Fictitious Domain Methods for Flows Containing Rigid Particles

Modelling of particulate flows is one of the most difficult and often misunderstood ares of Computational Fluid Dynamics. There is a variety of proposed models, however, none of them is based on a solid theoretical foundation, thoroughly verified in experiments. Therefore, it is very important to approach the problem by solving directly the incompressible Navier–Stokes equations in a domain filled with rigid particles and try to extract some useful average characteristics of such flows. This is an extremely difficult computational task and there are very few available methods that could be applied. In this talk we describe the variant of the fictitious domain method (FDM) which was proposed by our group. Several validation examples of flows with rigid particles are also presented. The focus of the talk will be on the development of a particular version of the algorithm for the simulation of micron-size particles in pipes and bifurcations whose characteristic size is of the order of millimeters. This particular application comes from the need to predict the deposition rate of drugs in the upper air ways. Because of the clear separation of scales, it was possible to develop a technique using two sliding grids (corresponding to the two different scales)—one linked with the particle and the other one with the pipe. The flow at the macro scale is first resolved without the particle and then the information is used as a boundary condition for the micro-scale problem. The two problems can be linked (if needed) in an iterative fashion to account for the effect of the particles on the flow. The numerical examples include particles of spherical and ellipsoidal shape.

BIJAN MOHAMMADI, Univ. Montpellier II
Simulation and design for coastal engineering

We propose an overview of our simulation and design platform for coastal engineering applications. Particular emphasis will be given to anti-erosion devices for sandy beaches. We also take this opportunity to describe a global optimization alternative useful for multi-criteria problems. The question of generating non-convex Pareto fronts will be addressed.

NILIMA NIGAM, McGill University, 805 Sherbrooke West, Montreal
The nonlinear critical layer for Kelvin modes on a vortex

We consider the propagation of neutral modes along a vortex with radial velocity profile. In the linear inviscid stability theory for swirling flows, modes which become singular for some critical radial distance are significant. The singularity could be dealt with using nonlinear effects within a thin critical layer, and/or by adding viscosity. At high Reynolds number, the nonlinear effects become important. In this talk we present the scaling and equations which govern the nonlinear critical layer. We then present a solution by means of the method of characteristics of the governing inviscid system of PDE. We finally present modes which are not possible in a linear theory, and some numerical results.

This is joint work with S. A. Maslowe.

JEAN-LUC THIFFEAULT, University of Wisconsin–Madison
The Role of Walls in Chaotic Mixing: Experimental Results

We report on experiments of chaotic mixing in a closed vessel, in which a highly viscous fluid is stirred by a moving rod. We analyze quantitatively how the concentration field of a low-diffusivity dye relaxes towards homogeneity, and observe a slow algebraic decay, at odds with the exponential decay predicted by most previous studies. Visual observations reveal the dominant role of the vessel wall, which strongly influences the concentration field in the entire domain and causes the anomalous scaling. A simplified 1-D model supports our experimental results. Quantitative analysis of the concentration pattern leads to scalings for the distributions and the variance of the concentration field consistent with experimental and numerical results. We also discuss possible ways of avoiding the limiting role of walls.

This is joint work with Emmanuelle Gouillart, Olivier Dauchot, and Stephane Roux.

MARTIN VOHRALIK, Université Paris 6, 175 rue du Chevaleret, 75013 Paris, France
A unified framework for optimal a posteriori error estimation in different numerical methods

We present a unified framework which allows for optimal a posteriori error estimation in approximation of linear second-order elliptic partial differential equations by different numerical methods. In particular, the continuous and discontinuous Galerkin finite element, mixed finite element, finite volume, and finite difference methods are considered. Fully computable upper bounds are derived, so that the estimators allow for the overall energy error control in addition to the adaptive mesh refinement, which is supported by the local efficiency of the estimators. Some robustness results and the case of inexact solution of the associated linear systems are also mentioned. Numerical results illustrate the theory.

BRIAN WETTON, Mathematics Department, UBC

Stack level computational models of polymer electrolyte membrane hydrogen fuel cells

A model of steady state operation of Polymer Electrolyte Membrane Fuel Cell (PEMFC) stacks with straight gas channels is presented. The model is based on a decoupling of transport in the down-channel direction from transport in the cross-channel plane. Further, cross-channel transport is approximated heuristically using one-dimensional processes. The model takes into account the consumption of reactants down the channel, two-phase transport in the Gas Diffusion Electrodes (GDE), the effect of membrane hydration on its conductivity, water crossover through the membrane, the electrochemistry of the oxygen reduction reaction, thermal transport within the Membrane Electrode Assembly (MEA) and bipolar plates to the coolant, heat due to reaction and condensation and membrane resistance, electrical interaction between unit cells due to in-plane currents in the bipolar plates, and thermal coupling of unit cells through shared bipolar plates. The model is a nonstandard system of non-smooth boundary value Differential Algebraic Equations (DAEs) with strong, nonlocal coupling. A discretization of the system and a successful iterative strategy are described. Representative computational results, validation against existing experimental data and a numerical convergence study are shown.