FSI2018 Abstracts

Dynamics of the particulate Pulse Detonation Engine (PDE)

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There is interest to introduce liquid fuel into the design and operation of the pulse detonation engine (PDE) for the propulsion system due to their advantages comparing to the gaseous engine. These advantages include a vastly higher energy density, safer and smaller storage tank, etc. To take these advantages and use them efficiency, it is necessary to gain understanding on how the liquid fuel work and perform in the PDE. In this study, numerical simulations are performed for the different working conditions of liquid fueled PDE to further understand the physical and chemical phenomena occurring inside the detonation chamber and the outputs of interest, as well as to obtain an optimal working condition region for an efficiency and smooth operation. The working conditions include supplied inlet air temperature, inlet air velocity and injected fuel mass flow rate. In particular, the intensive numerical simulation is implemented for three main processes of the liquid PDE, which are the injection, deflagration to detonation transition process and detonation propagation process. The Eulerian–Lagrangian approach with sub-models is employed for the vapor and liquid phase of the system. The obtained results show that the liquid droplets might be completely evaporated during the injection process, which depends on the working conditions. The deflagration wave can successfully transit to detonation wave via both complete and incomplete evaporation cases. The level of fuel vapor (fuel equivalence ratio) in the pre-evaporation plays an important role in the success of the DDT process. The deflagration can successfully transit to the detonation for the global equivalence ratio of up to 4.0 for a certain level of fuel vapor in the pre- evaporation process, while it cannot be transited to detonation waves if the fuel vapor is either too lean or too rich.

A fast parallel algorithm for direct simulation of particulate flows using conforming grids

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This study presents a development of the direction splitting algorithm for problems in complex geometries proposed in [1] to the case of flows containing rigid particles. The main novelty of this method is that the grid can be very easily fit to the boundaries of the particle and therefore the spatial discretization is very accurate. This is made possible by the direction splitting algorithm of [1]. It factorizes the parabolic part of the operator direction-wise and this allows discretizing in space each of the one-dimensional operators by adapting the grid to fit the boundary only in the given direction. Here we use a MAC discretization stencil but the same idea can be applied to other discretizations. Then the equations of motion of each particle are discretized explicitly and the so-computed particle velocity is imposed as a Dirichlet boundary condition for the momentum equations on the adapted grid. The pressure is extended within the particles in a fictitious domain fashion. The presentation will also include

some results on direct simulations of fluidized beds involving thousands and millions of particles.

[1] Ph. Angot, J. Keating, and P. Minev. A direction splitting algorithm for incompressible flow in complex geome- tries. Comput. Methods Appl. Mech. Engrg, 117:111–120, 2012.

Numerical techniques for the simulation of discrete fracture networks

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Different formulations and numerical approximations are presented for the simulation of discrete fracture networks in two dimensions. In all cases the fracture flow is represented by a one-dimensional flow inside the fractures coupled with a two-dimensional flow through the porous media. The different formulations are compared in terms of computation of total flux, conservation properties and size of global system of equations. We compare H1 approximation, H(div) approximation, H(div) approximation with MHM (Multiscale Hybrid Mixed) multiscale reduction, and H(div) spaces with SBFem enhanced resolution at the fracture tips. The different formulations are implemented using the NeoPZ programming environment that is freely available on github.

Elastic contact in fluid-structure interactions

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In this talk we address the following fundamental question: what happens if an elastic ball is falling in a container with a viscous fluid towards a rigid wall on the bottom? Will it come to contact? Or will there always remain a thin fluid film between wall and bottom? Will the ball bounce off? Or will the ball come to rest and stick?

We start by giving an overview on various results on this topic, computationally, analytically and experimentally. Then in a second part we numerically investigate this challenging problem.

The possible contact between ball and boundary is a fundamental difficulty for established discretization schemes as it involves topology changes in the domain. For describing the interaction problem between elastic solid and fluid we shortly introduce the ALE approach and discuss its shortcomings in terms of modeling contact. Then, we introduce an alternative Eulerian approach that is well suited for contact problems. This Eulerian approach however brings along new difficulties with respect to discretization.

On the stability and accuracy of partially and fully implicit schemes for phase field modeling

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Implicit boundary and anisotropic mesh adaptation for multiphase flow simulations

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A wider use of numerical simulation is still depending on meshing and adaptive meshing capabilities when complex geometry, multi-domain, moving interface and multiphase flow are involved. This task becomes more and more difficult when it is combined with a posteriori adaptive meshing or/and dealing with moving interfaces and boundary layers and also when running on massively parallel computers. In order to overcome the lack of flexibility of the common body fitted method, the alternative proposed here, is based on an implicit representation of the interfaces by a local distance function using a hyperbolic tangent filter. Therefore, the geometries can be interpolated and contribute to the numerical error which is detected by an a posteriori error estimate. This approach favors the full usage of anisotropic adaptive meshing techniques providing an optimal capture of the interfaces within the volume mesh, whatever is the complexity of the geometry involved.
From the flow solver side, unstructured meshes with highly distorted elements (however solution aligned) need to rely on a robust solution framework. The interface condition transfer is enforced by following the immersed boundary/volume (IVM) methodologies for fluid/fluid and or fluid/structure interaction. The proposed multiphase flow solver, including the convected local level set technique is based on a stabilized finite element method (VMS) that can afford with anisotropic meshing even with high aspect ratio elements. The general stabilization approach including the interface stabilization term and the dynamic will be introduced with a quasi-optimal calculation of the stabilization parameter for anisotropic finite elements. The multiphase Navier Stokes error estimation and the associated metric calculation will be discussed and various application examples will be proposed.

Sperm and ciliary motility and in viscous and viscoelastic media

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The motility of sperm flagella and cilia are based on a common physiological structure capable of generating a wide range of dynamical behavior. We describe a fluid-mechanical model for sperm and cilia coupling the internal force generation of dynein molecular motors through the passive elastic axonemal structure with the external fluid mechanics. As shown in numerical simulations for motile sperm, the model's flagellar waveform depends strongly on viscosity as well as dynein strength. We describe a Lagrangian mesh method for modeling complex fluids where the fluid viscoelasticity is represented by a discrete network of Maxwell elements. The rheological properties of the Lagrangian mesh fluid are compared with an Oldroyd-B model for complex fluids. We show simulation results from immersed boundary models for peristalsis and sperm motility in Lagrangian mesh.

Local lubrication model for spherical particles within an incompressible Navier-Stokes Flow

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The lubrication effects are short-range hydrodynamic interactions essential to the suspension of the particles, and are usually underestimated by direct numerical simulations of particle laden flows. In this talk, we propose a lubrication model for a coupled volume penalization method and discrete element method solver which estimates the unresolved hydrodynamic forces and torques in an incompressible Navier-Stokes flow. Corrections are made locally on the surface of the interacting particles without any assumption on the global particle shape. The numerical model has been validated against experimental data and is shown to perform as well as existing numerical models that are limited to spherical particles.

Some numerical techniques to solve Bernoulli's free boundary problem

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We consider the free boundary Bernoulli problem, which can be viewed as a prototype of stationary free boundary problems. The main theoretical properties of this problem are first presented, together with different numerical techniques. A special attention will be given to rough domains.

Free boundary problems and variational inequalities

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We formulate a class of free boundary problems as variational inequality. Examples of such include the Stefan problem and the obstacle problem and the American option pricing. Numerical algorithms are developed and analyzed.

A least squares augmented method for fluid and porous media couplings

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Simulations of fluid and porous media couplings are important and challenging because of different governing equations and complicated interface conditions such as BJ and BJS relations. Most of numerical methods in the literature are based on finite element formulations in which the interface conditions are incorporated in the variational forms. One consequence is that the large errors across the interface due to low regularity of the solution if the mesh is not aligned with the interface. The large discrete system makes harder to use fast solvers.

In this talk, we propose a finite difference approach with unfitted meshes. By introducing several augmented variables along the interface, we can decouple the original problem as several Poisson/Helmholtz equations with intermediate jump conditions in the solution and the normal derivatives. One obvious advantage is that a fast Poisson/Helmholtz solver can be utilized. The augmented variables should be chosen such that the Beavers-Joseph-Saffman (BJS) and other interface conditions are satisfied. Another significant strategy is to enforce the divergence condition at the interface from the fluid side. We have shown that the original and transformed systems are equivalent. Because the interface conditions are enforced in strong form, we have observed second order convergence for both of the velocity and the pressure for our constructed non-trivial analytic solutions with circular interfaces. The proposed new method has also been utilized to simulate different flow/porous media setting with complicated interfaces which leads to some interesting simulations results such as effect of corners, orientation effect etc.