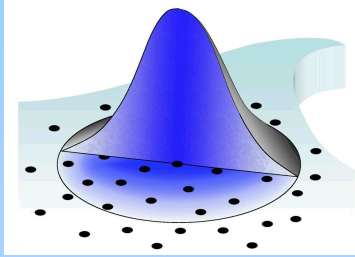


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## 7<sup>th</sup> International SPHERIC Workshop

By Andrea COLAGROSSI, member of the Local Organising Committee

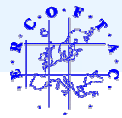
A joint Australian-Italian team proudly hosted the 7<sup>th</sup> International SPHERIC Workshop at the Monash University Prato Centre in Italy over May 29-31, 2012. The multi-institute, multi-continent team consisted of Prof. Joe Monaghan, Dr. Jules Kajtar and Jenny Monaghan from Monash University, Melbourne, Australia; Dr. Andrea Colagrossi, Dr. Salvatore Marrone and Dr. Benjamin Bouscasse from INSEAN, Rome, Italy; and Prof. Stefano Sibilla from the University of Pavia, Italy. The Monash University Prato Centre is housed in the elegant 18<sup>th</sup> Century Palazzo Vaj, and the historic centre of Prato (approximately 20 km northwest of Florence) provided a scenic backdrop for the event.

The theme of the workshop was “green”, and every attempt was made to reduce the workshops impact on the environment. To this end, the conference proceedings were not delivered in print-form (and only on USB drives), the conference bags were simple and reusable calico bags, and even the pens were made of recycled materials.



The 100 or so participants were treated to a busy but stimulating schedule of presentations. Some of the presentation topics included multi-fluid treatments, geotechnical applications, solids and fracture mechanics, validation, astrophysical applications, boundary conditions, turbulence modeling, alternative formulations, maritime applications, high performance computing, and hydraulic applications. Two keynote lectures were given. The first, entitled “Particles for fluids: SPH methods as a mean-field flow” was presented by Mario Pulvirenti from the University of Rome, and the second, entitled “Towards interactive SPH applications and post-processing” was presented by John Biddiscombe from the Swiss National Supercomputing Centre (CSCS).

A new feature of this year’s workshop was the addition of two workshop-wide discussion sessions. The topics of the two hour-long sessions were “Ideas about viscosity” and “Ideas about the treatment of boundaries”. Prof. Joe Monaghan chaired both sessions, and they produced lively discussion about the state-of-the-art in both fields.



The workshop banquet is always a highlight on the agenda, and this year's stunning affair did not fail to please. Attendees were treated to a delicious three-course dinner and plenty of wine at the majestic Medici Villa, built in 1596, situated in Artimino (20 minutes west of Florence). At the banquet, first place for the student prize (an Apple iPad sponsored by HYDROCEAN) was awarded to Terrence Tricco. Arno Mayrhofer and Jannes Kordilla were awarded second and third place respectively, and received a cash prize (sponsored by Monash University) for their efforts. The workshop featured 17 high-quality student talks, almost one third of the total number.

After the workshop, on Friday June 1, twelve students participated in the annual SPH training day. Paul Groenonboom and Ben Rogers presented lectures on the theory and application of SPH in the morning. The afternoon session featured hands-on workshops conducted by Ben Rogers, Alex Crespo, Jose Dominguez and John Biddiscombe on DualSPHysics (an SPH CPU-GPU coupled solver), and Paraview PV-Meshless (a visualization package).

The workshop organizers wish to thank all those that attended for helping to continue the proud tradition of productive and successful SPHERIC workshops.

Contact: [a.colagrossi@insean.it](mailto:a.colagrossi@insean.it)

### DAY 1: Tuesday 29 May 2012

*Keynote lecture: Prof. M. Pulvirenti, Dipartimento di Matematica, Universita' di Roma La Sapienza.*

Particles for fluids – SPH methods as a mean-field flow.

#### *Session 1: Multi-Fluids*

*Chair: B.D. Rogers*

- *SPH modelling of two-phase bubbly flows.* E. Torti, S. Sibilla
- *SPH multiphase simulation of bubbly flows.* N. Grenier, M. Kerhuel, D. Le Touzé, A. Colagrossi, G. Colicchio, M. Antuono, D. Zuzio
- *Surface tension and wetting phenomena with SPH.* T. Breinlinger\*, A. Hashibon, T. Kraft
- *Contact line hydrodynamics with SPH.* S. Adami, X.Y. Hu, N.A. Adams

#### *Session 2: Geotechnical Applications*

*Chair: X.Y. Hu*

- *SPH non-Newtonian model for ice sheet and ice shelf dynamics.* A.M. Tartakovsky, W. Pan, J.J. Monaghan
- *Simulation of film and droplet flow on wide aperture fractures using smoothed particle hydrodynamics.* J. Kordilla\*, A. Tartakovsky, T. Geyer
- *Application of SPH to erosion and excavation problems on the examples of jet grouting and offshore engineering.* B. Stefanova, J. Bubel, J. Grabe
- *A simple SPH model of water-soil interaction in porous media.* C. Ulrich, T. Rung

#### *Session 3: Solids and Fracture Mechanics*

*Chair: P.K. Stansby*

- *SPH simulation of granular material collapses.* E. Paris, L. Minatti
- *Towards simulations of abrasive flow machining.* C. Nutto, C. Bierwisch, H. Lager, M. Moseler
- *A modified Godunov SPH method for materials with strength.* A. Connolly\*, L. Iannucci
- *Dynamic refinement for SPH simulations of post-failure flow of non-cohesive soil.* Y. R. López, D. Roose, C. R. Morfa

#### *Session 4: Validation*

*Chair: A.M. Tartakovsky*

- *Flow prediction of reactive rotational molding using smoothed particle hydrodynamics method.* S. Rivière\*, S. Farzaneh, A. Tcharkhtchi, S. Khelladi, F. Bakir
- *SPH simulations and experiments of sloshing in an egg-shaped shell.* J. Grant\*, M. Prakash, S.E. Semercigil, O.F. Turan
- *On the use of a time-dependent driving force in SPH simulations.* Sh. Khorasanizade\*, J.F. Pinto, J.M.M. Sousa

- *Incompressible smoothed particle hydrodynamics: proposition and validation of a fully-explicit algorithm.* D.A. Barcarolo\*, D. LeTouzé, F. deVuyst

- *Modeling of gravity wave viscous attenuation.* A. Colagrossi, A. Souto-Iglesias, M. Antuono

### **Session 5: Astrophysical Applications**

**Chair:** J.J. Monaghan

- *Hyperbolic divergence cleaning for SPH.* T. S. Tricco\*, D. J. Price
- *Modelling magnetic fields and turbulence with SPH.* D. J. Price
- *An algorithm for dusty gas with SPH.* G. Laibe, D. J. Price, B. A. Ayliffe

### **Discussion: Ideas about viscosity**

**Chair:** J.J. Monaghan

## **DAY 2: Thursday 9 June**

### **Keynote lecture: Dr J. Biddiscombe, Swiss National Supercomputing Center**

Towards interactive SPH applications and post-processing

### **Session 6: Boundary Conditions and Validation**

**Chair:** A. Souto-Iglesias

- *2D and 3D sloshing simulation by SPH.* M. Leonardi\*, S. Manenti, S. Sibilla
- *SPH modeling of non-rectangular channel flows with open boundaries.* K.-H. Chang\*, T.-J. Chang
- *Study of differential operators in the context of the semi-analytical wall boundary conditions.* A. Mayrhofer\*, B. D. Rogers, D. Violeau, M. Ferrand
- *Apply C1 consistency to SPH with free surface.* H. Xu\*, M. H. Dao, E. S. Chan, P. Tkalic
- *SPH modelling of viscous flows around cylinders from  $Re=10$  to  $Re=1000$ .* S. Marrone, M. Antuono, A. Colagrossi, G. Colicchio, G. Graziani

### **Session 7: Turbulence Modelling**

**Chair:** M. Gomez Gesteira

- *Turbulent coherent structures under breaking water waves.* R. Jalali-Farahani, R. A. Dalrymple, A. Hérault, G. Bilotta
- *A SPH model for incompressible turbulence.* X.Y. Hu, N.A. Adams
- *SPH simulations of 2D turbulence driven by stirrers.* A. Valizadeh, J.J. Monaghan
- *Advective and diffusive turbulent mixing.* J.J. Monaghan, J.B. Kajtar

### **Session 8: Alternative Formulations**

**Chair:** P. Groenenboom

- *On the use of numerical diffusive terms in weakly-compressible SPH schemes.* M. Antuono, A. Colagrossi, S. Marrone
- *SPH-ALE for simulations of rotor-stator interactions.* M. Neuhauser\*, J.-C. Marongiu, F. Leboeuf, M. Rentschler, E. Parkinson
- *FPM simulations of a 3D impinging jet on a flat plate comparison with CFD and experimental results.* C. Vessaz\*, E. Jahanbakhsh, F. Avellan
- *Remeshed Particles: a robust and efficient method for multiphysics simulations.* W.M. van Rees\*, P. Koumoutsakos

### **Session 9: Maritime Applications**

**Chair:** D. Violeau

- *Use of SPHERA code to investigate local scouring effects induced by fluvial structures downstream a barrage.* G. Agate, R. Guandalini, S. Manenti, S. Sibilla, M. Gallati
- *SPH modelling of propeller induced harbour-bed erosion by a container vessel.* C. Ulrich, T. Rung
- *SPH simulations of bow waves dynamics.* B. Bouscasse, S. Marrone, A. Colagrossi, R. Broglia
- *Using SPHysics to simulate a Wigley hull in head waves.* M. Pearce\*, G. Thomas, D. Hudson

### **Session 10: High Performance Computing**

**Chair:** D. J. Price

- *Efficient parallelisation of 3D SPH scheme.* D. Guibert, M. DeLefte, G. Oger, J.-G. Piccinali

- *New OpenMP-MPI-CUDA implementation for parallel SPH simulations on heterogeneous CPU- GPU clusters.* J. M. Domínguez\*, A. J. C. Crespo, M. Gomez-Gesteira, D. Valdez-Balderas, B. D. Rogers
- *A journey from single-GPU to optimized multi-GPU SPH with CUDA.* E. Rustico, A. Hérault, G. Bilotta, C. del Negro, G. Gallo, R.A. Dalrymple
- *Parallelisation of a finite volume particle method code.* M. Basa, L. Lobovsky, N.J. Quinlan

*Discussion: Ideas about the treatment of boundaries*

*Chair: J.J. Monaghan*

### **DAY 3: Friday 10 June**

#### **Session 11: Boundary Conditions and Validation**

*Chair: D. Le Touzé*

- *Use of complex inlet boundary conditions for accelerated studies of green water events.* C. Pâkozdi, C. T. Stansberg
- *Absorbing inlet/outlet boundary conditions for 2D SPH turbulent free-surface flows.* O. Mahmood, D. Violeau, C. Kassiotis, B.D. Rogers, M. Ferrand
- *On the boundary condition enforcement in SPH methods.* L. M. González, J. L. Cercós, F. Macia
- *A diffusion based shifting algorithm for incompressible smoothed particle hydrodynamics: Validation with cases involving slamming bodies and cylinder exit.* A. Skillen, S. Lind, B.D. Rogers, P.K. Stansby

#### **Session 12: Multi-Fluids**

*Chair: N.J. Quinlan*

- *SPH multi-fluid model with interface stabilization based on a quasi-buoyancy correction.* A.C.H. Kruisbrink, F.R. Pearce, T. Yue, K.A. Cliffe, H.P. Morvan
- *A multiphase incompressible-compressible smoothed particle hydrodynamics method.* S.J. Lind, P.K. Stansby, B.D. Rogers
- *SPH for two-phase fluid flow including cavitation.* P. Groenenboom
- *A consistent particle method for simulation of multiphase flows with high density ratios.* A. Khayyer, H. Gotoh

#### **Session 13: Alternative Formulations**

*Chair: A. Colagrossi*

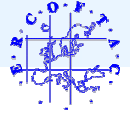
- *Development of SPH variable resolution using dynamic particle coalescing and splitting.* R. Vacondio, B. D. Rogers, P. K. Stansby, P. Mignosa, J. Feldman
- *Development of the finite volume particle method for internal flow with rigid body dynamics.* N.J. Quinlan, L. Lobovsky, M. Basa, R.M. Nestor
- *Third-generation RSPH in 3D.* S. Børve
- *Development and validation of a SPH model using discrete surface elements at boundaries.* A. Amicarelli, G. Agate, R. Guandalini
- *An improved consistent 3D particle method for enhanced wave impact calculations.* H. Gotoh, A. Khayyer

#### **Session 14: Hydraulic Applications**

*Chair: J.-C. Marongiu*

- *Experimental and numerical modeling of the impulsive dynamics of an underwater non-cohesive sediment deposit subjected to a gaseous jet.* S. Manenti, S. Sibilla, M. Gallati, G. Agate, R. Guandalini
- *3-D coastal inundation simulation using a shallow-water solver.* J. Zhao, D. Le Touzé, L. Gentaz, P. Ferrant
- *Improved accuracy in modelling armoured breakwaters with SPH.* C. Altomare, X. F. Gironella, A. J. C. Crespo, J. M. Domínguez, B. D. Rogers
- *Simulation of dam-break flow in channel expansion with coupled 2-D/3-D SPH model.* E. Džebo, D. Žagar, M. Četina, G. Petkovšek
- *SPH benchmarking: a comparison of SPH variants on selected test cases within the NextMuSE initiative.* D. Le Touzé, D. A. Barcarolo, M. Kerhuel, F. Leboeuf, J. Caro, F. Le, N. Quinlan, L. Lobovsky, M. Basa, A. Colagrossi, S. Marrone, J.-C. Marongiu, M. De Leffe

\* denotes eligible for student prize



## Mixed Hyperbolic/Parabolic Divergence Cleaning for SPH

T.S. Tricco & D.J. Price, Monash Centre for Astrophysics, Monash University, Melbourne, Victoria, 3800, Australia

This work received the award for best student paper (Libersky Prize) at the 7<sup>th</sup> Int. SPHERIC Workshop, Prato (Italy), June 2012 (Tricco and Price, 2012b).

In numerical magnetohydrodynamics (MHD), it is important to uphold the divergence-free constraint of the magnetic field, and doing so is one of the key challenges in performing successful numerical MHD simulations. In this research, an SPH formulation of the hyperbolic/parabolic divergence cleaning method by Dedner *et al.* (2002) has been constructed. This formulation retains the conservative nature of SPH, ensuring stability of the algorithm across sharp density contrasts, at free surfaces, and for long term evolution. The cleaning algorithm is found to reduce divergence errors by an order of magnitude for all tests and applications considered (Tricco, Price, 2012a).

The hyperbolic/parabolic divergence cleaning method of Dedner *et al.* (2002) functions in two respects. First, a diffusion term acting on  $\nabla \cdot \mathbf{B}$  is present which removes divergence of the field. Second, any individual sources of divergence are diluted by spreading them throughout the field. This is achieved by coupling a new scalar field  $\psi$ , to the magnetic field which propagates divergence via the solution of a wave equation. By spreading the divergence in this manner, the impact of any single large source of divergence is diminished, and also the surface area of the divergence in the field is increased allowing the diffusion term to be more effective.

Our implementation for SPMHD is constructed by considering the energy contained in the  $\psi$  field and constraining that the total energy of the system be conserved. This energy term can be included as part of the system Lagrangian, and doing so leads to SPMHD equations of the form

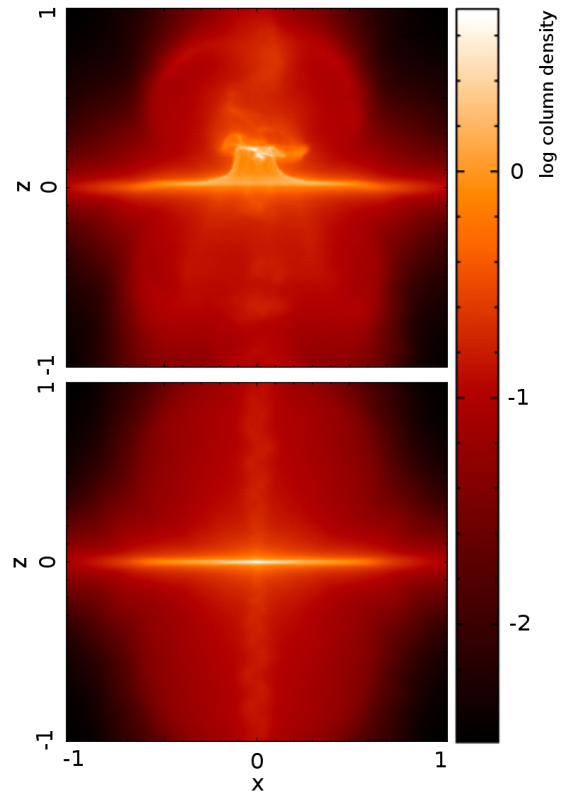
$$\begin{aligned} \frac{d\mathbf{B}_a}{dt} &= -\rho_a \sum_b m_b \left[ \frac{\psi_a}{\rho_a^2} + \frac{\psi_b}{\rho_b^2} \right] \nabla W_{ab}, \\ \frac{d\psi_a}{dt} &= \frac{c_h^2}{\rho_a} \sum_b m_b (\mathbf{B}_a - \mathbf{B}_b) \cdot \nabla W_{ab} - \frac{\sigma c_h^2}{h} \psi_a \\ &\quad + \frac{\psi_a}{2\rho_a} \sum_b m_b (\mathbf{v}_a - \mathbf{v}_b) \cdot \nabla W_{ab}. \end{aligned}$$

The speed of the wave propagation is given by  $c_h$ , and is chosen to equal the fast MHD wave speed so that it obeys the CFL timestepping condition. The strength of the diffusion term is regulated by the dimensionless parameter  $\sigma$ , for which the best empirically determined values are 0.2–0.3 in 2D and 0.8–1.2 in 3D.

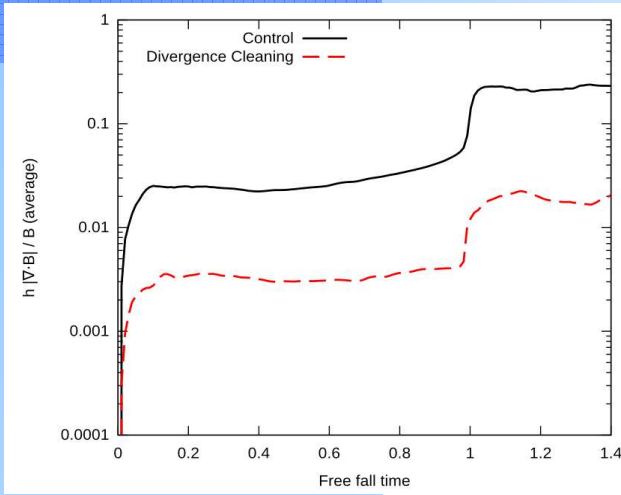
The above equations differ from the continuum equations of Dedner *et al.* by the addition of a  $-1/2 \psi (\nabla \cdot \mathbf{v})$  term. This term is necessary for the preceding equations to

strictly conserve energy when included as part of the full MHD system of equations.

The effectiveness of the constrained divergence cleaning algorithm is demonstrated by applying it to simulations of the formation of a protostar from the gravitational collapse of a magnetised molecular cloud core. This problem is numerically challenging, as the collapsing gas accumulates and generates large divergence errors around the protostar in the centre of the accretion disc. This can cause the protostar and surrounding material to erupt out of the disc (which is not indicative of how stars actually form). Our cleaning algorithm is effective at removing these errors, and stabilises an otherwise disrupted system (figure 1) with average divergence error reduced by an order of magnitude (figure 2). This has allowed our simulations, for the first time with SPMHD, to capture the launch of magnetically propelled jets of material (Price, Tricco, Bate, 2012).



**Figure 1** – Log of column density at  $t=1.1$  free fall times from simulations of a forming star. Without the divergence cleaning algorithm (top panel), the divergence error causes the protostar and surrounding accretion disc to be disrupted. With divergence cleaning (bottom panel), the divergence errors remain small enough to keep the star stable in its disc, and captures the launch of magnetically propelled jets.



**Figure 2** – Average divergence error for the star formation test case. Without cleaning, divergence error in the magnetic field can spike to 20–30%, whereas cleaning maintains error to ~1%.

The hyperbolic/parabolic divergence cleaning method may be generally applied to any vector field. Therefore, a formulation was considered for removing divergence of the velocity field with intended application to WCSPH simulations (Tricco and Price, 2012b). WCSPH is often used to model incompressible fluid flow, however it forgoes true incompressibility for simplicity of implementation by using the standard Lagrangian SPH formalism with a stiff equation of state to limit density variations (typically ~1%). If the density is integrated using the continuity equation, then changes in density are linked to the divergence of the velocity field. Therefore, it would be expected that a closer representation of incompressibility would be achieved by minimising this quantity.

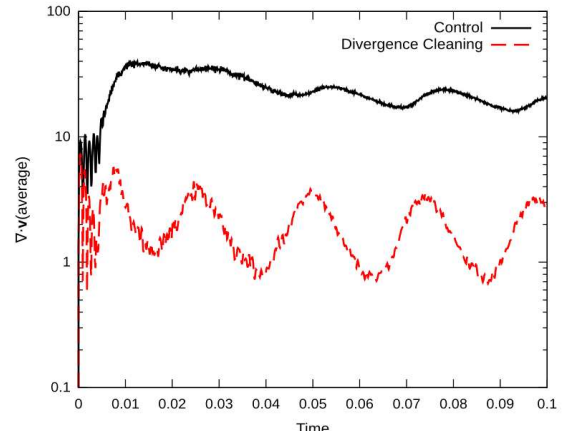
The SPH velocity divergence cleaning algorithm is constructed in a manner similar for the magnetic field. An energy term for the  $\psi$  field is defined, and is used to construct the constrained SPH cleaning equations. This energy term differs from the magnetic field cleaning implementation because the units of  $\psi$  are linked to the vector field it is coupled to. Additionally, in this case, factors of  $\rho$  and  $\rho^{-1}$  are introduced to the respective cleaning equations, yielding

$$\frac{d\mathbf{v}_a}{dt} = -\sum_b m_b \left[ \frac{\psi_a}{\rho_a^2} + \frac{\psi_b}{\rho_b^2} \right] \nabla W_{ab},$$

$$\frac{d\psi_a}{dt} = c_h^2 \sum_b m_b (\mathbf{v}_a - \mathbf{v}_b) \cdot \nabla W_{ab} - \frac{\sigma c_h^2}{h} \psi_a.$$

These equations conserve both energy and momentum. The wave speed is chosen to equal the speed of sound so that it adheres to the CFL stability criterion.

The velocity divergence cleaning algorithm was tested using an oscillating elliptic water drop. The circular drop has initial velocity compressing it along one axis, but an added central force reverses the stretching of the drop, causing it to rebound alternately along the  $x$ - and  $y$ -axes. Applying divergence cleaning was found to reduce average divergence of the velocity field by an order of magnitude (figure 3), resulting in the magnitude of density variations to be reduced by half (Tricco, Price, 2012b). Kinetic energy dissipation was found to be negligible. This test also demonstrates the constrained cleaning algorithms ability to handle free surfaces.

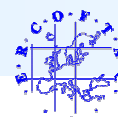


**Figure 3** – The average divergence of the velocity field for the oscillating elliptic water drop test is reduced by an order of magnitude when divergence cleaning is applied.

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### References

- Dedner, A., Kemm, F., Kroner, D., Munz, C.-D., Schnitzer, T., Wessberg, M. (2002), *Hyperbolic divergence cleaning for the MHD equations*, J. Comp. Phys. **175**:645.
- Tricco, T.S., Price, D.J. (2012a), *Constrained hyperbolic divergence cleaning for smoothed particle magnetohydrodynamics*, J. Comp. Phys. (submitted).
- Price, D.J., Tricco, T.S., Bate, M.R. (2012), *Collimated jets from the first core*, MNRAS Letters, **423**:45.
- Tricco, T.S., Price, D.J. (2012b), *Hyperbolic divergence cleaning for SPH*, Proc. 7<sup>th</sup> SPHERIC Int. Workshop, pp. 115.



## Differential operators in the context of the semi-analytical wall boundary conditions

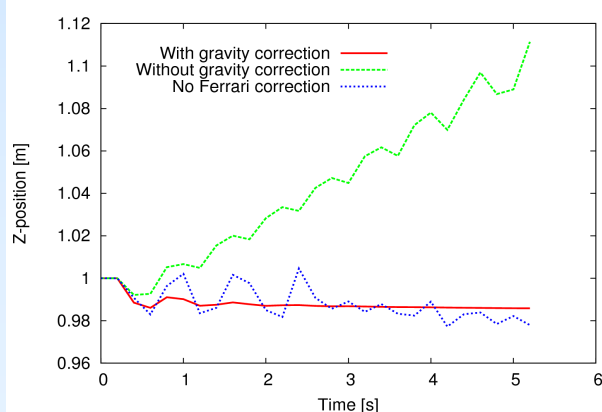
A. Mayrhofer & B.D. Rogers, School of MACE, University of Manchester, United Kingdom  
D. Violeau & M. Ferrand, LNHE, Electricite de France R&D, France

This work received the 2<sup>nd</sup> prize in the competition for the best student paper at the 7<sup>th</sup> Int. SPHERIC Workshop, Prato (Italy), June 2012 (Mayrhofer *et al.*, 2012).

Treating solid wall boundary conditions is still a big challenge in SPH. With the recent work of Ferrand *et al.* (2012) a promising framework for boundary conditions was introduced. One of its main features is a kernel renormalization factor which does not rely on the standard SPH quadrature rule. Additionally, the SPH differential operators are defined without neglecting the boundary terms which enables the correct imposition of boundary conditions as e.g. the shear stress.

In the presented paper the authors investigate these operators in continuous form with emphasis on the skew-adjoint property. Although the continuous operators are skew-adjoint even when boundaries are present the result cannot readily be extended to the discretized operators.

Due to the collocated nature of SPH it is susceptible to the checkerboard effect which manifests itself in form of numerical noise in the pressure field. In order to avoid this deficiency a volume diffusion term by Ferrari *et al.* (2009) is used. In the paper it is shown that this term can be related to the Reynolds averaged continuity equation when applying the gradient diffusion hypothesis. Besides this a modification is proposed for flows which are influenced by external forces. This is illustrated by a still water test case which exhibits free-surface detachment when the standard formulation is used, something that is avoided by the new formulation (see Figure 1).

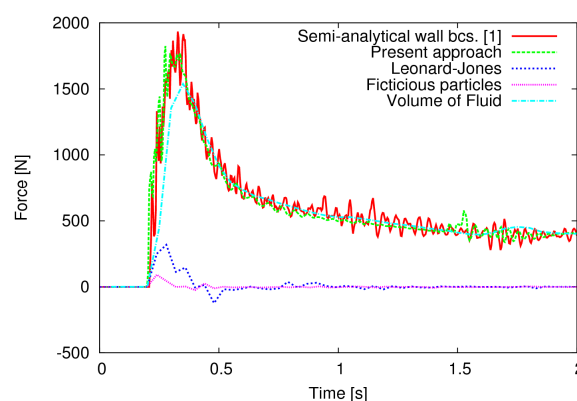


**Figure 1** – Free-surface height in an infinite channel.

The last theoretical contribution concerns the imposition of Robin-type boundary conditions. The paper presents a framework for imposing boundary conditions up to arbitrary order on boundary particles. This assumes that sufficient particles are in the support of such a particle.

Again a special treatment is proposed for flows with external forces. In the concrete case of the Navier-Stokes equations these boundary conditions are used to impose density and pressure via Neumann conditions.

Several simulations are shown in order to validate the theoretical concepts presented above. The first is a convergence study using the laminar Poiseuille flow which shows second order convergence if the time-independent continuity equation is used and first order otherwise. Additionally, a standing wave without viscosity was simulated showing about 1% loss of energy per period and an error in pressure of 1% and 7%, respectively, below a trough or crest. Finally, the dam-break over a wedge was used to compare the new approach to the one by Ferrand *et al.* (2012). The new approach shows a slightly less noisy pressure profile on the left wedge wall as shown in Figure 2.

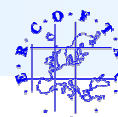


**Figure 2** – Force on left wedge wall.

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## Simulation of film and droplet flow on wide aperture fractures using SPH

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This work received the 3<sup>rd</sup> prize in the competition for the best student paper at the 7<sup>th</sup> Int. SPHERIC Workshop, Prato (Italy), June 2011.

Understanding small-scale flow processes in fractured geological media is crucial for the management of groundwater resources and nuclear waste disposal sites. As volume-effective flow equations commonly applied to simulate flow in these large-scale systems neglect important flow features SPH provides a robust numerical alternative to investigate the highly dynamic interfaces and intermittent flow processes.

We simulated free-surface droplet flow on smooth surfaces including the effect of surface tension (Tartakovsky & Meakin, 2005) and random thermal fluctuations.

Critical contact angles, i.e. at the onset of motion, are shown to reproduce the quadratic non-linear relationship between the ratio of receding and advancing angle and the Bond number as shown by ElSherbini (2004) in laboratory experiments.

Transient dynamics are verified via the dimensionless scaling proposed by Podgorski et al. (2001) for a wide range of Reynolds numbers and wetting conditions that are likely to occur in the investigated systems. It is shown that on initially dry surfaces adsorbed films may develop (see figure 1) and that the trailing film thickness depends on static contact angles and Reynolds numbers (see figure 2). Simulations with wet surfaces are shown to strongly increase flow velocities and are therefore an essential part of the flow dynamics.

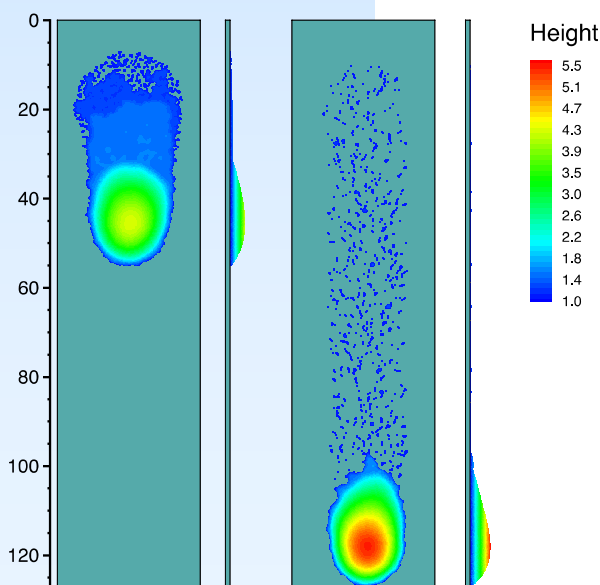


Figure 1 – Trailing films on dry surfaces.

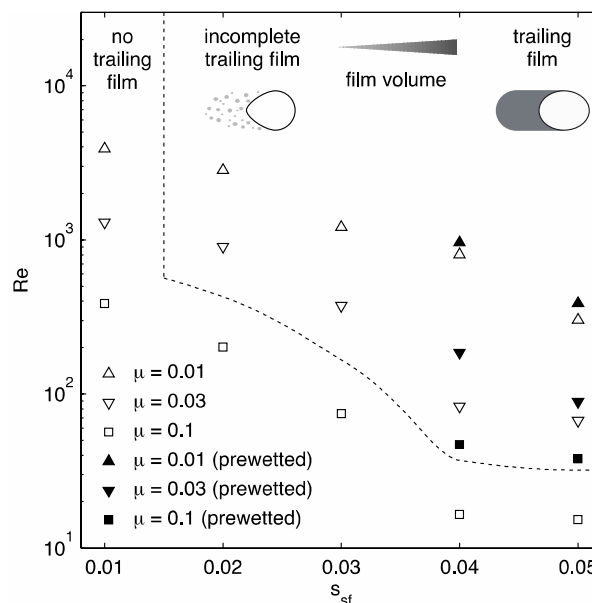


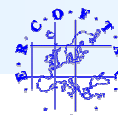
Figure 2 – Linear Flow regimes for various flow conditions (from Kordilla et al., 2012).

The effect of random thermal fluctuations added to the momentum equations via the fluctuation-dissipation theorem has been investigated and applied to simulation of droplets in a critical state. Results indicate no strong influence at the current model discretization but are believed to be of importance for the unified simulation of adsorbed films and droplets at higher resolutions.

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## SPH-ALE for floating block stability and ice accumulation in open-channels

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River ice jams can cause flood events with major social, economic, and ecological impacts. Unlike open water floods, which can often be predicted days or weeks in advance, ice jam flooding is abrupt, leaving little time for mitigation strategies. Their annual cost to the Canadian economy has been estimated to be nearly \$100 million (USD).

When ice floes approach a stationary ice cover, they either accumulate at the leading edge or they are entrained underneath the cover by the flow. To understand the mechanisms behind ice floe accumulation, it is useful to determine under what flow conditions ice floes accumulate and under what conditions they are entrained. Dimensional analysis suggests that the critical upstream velocity,  $V_{cr}$ , for which submergence occurs is a function of gravitational acceleration  $g$ , upstream water depth  $H$ , block thickness  $t$ , block length  $L$ , fluid density  $\rho_f$  and solid density  $\rho_s$ . The relation can be non-dimensionalized and expressed in terms of a densimetric Froude number  $F_D$ , based on block thickness and density differences:

$$F_D = \frac{V_{cr}}{\sqrt{gt(1 - \rho_s / \rho_f)}} = f\left(\frac{t}{H}, \frac{t}{L}\right)$$

Depending on the block's geometry, a floating block may be entrained in one of two modes: vertical submergence (no rotation), or overturning as described in figure 1. To observe overturning in various flow regimes and to determine  $V_{cr}$ , a series of numerical simulations were run, varying  $V$  and  $t/H$ , while keeping  $t/L$  constant.

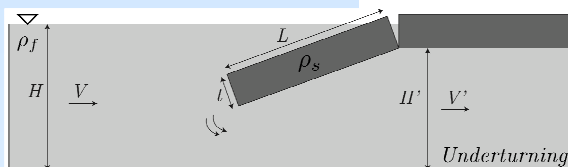


Figure 1 – Submergence by overturning. Notation.

Since it can be difficult for conventional Eulerian mesh methods to accurately track fluid-solid interfaces, a SPH-ALE formalism was used. First introduced by Vila (1999), and further developed by Marongiu et al. (2008) among others, SPH-ALE offers several advantages over grid-based methods. SPH's meshless nature poses no problems for defining fluid-solid interfaces. Furthermore, the ALE description enables the treatment of a boundary surface travelling with its own velocity, independent of the fluid velocity. Figure 2 shows one of several simulations demonstrating block submergence by overturning. The SPH simulation results, shown in figure 3, were compared with classical theory from three approaches whose predictions are generally in fair agreement with laboratory results.

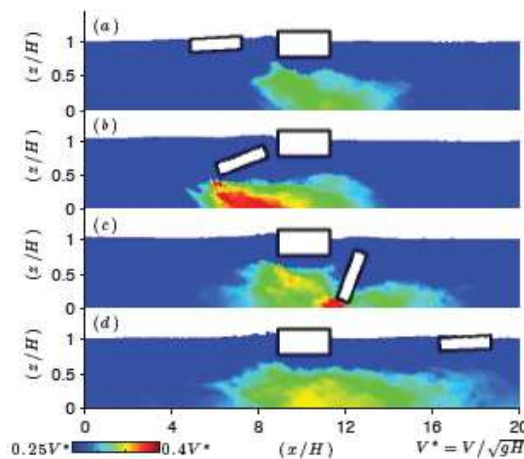


Figure 2 – SPH simulation at times 0, 2.5, 5.0, 7.5 s.

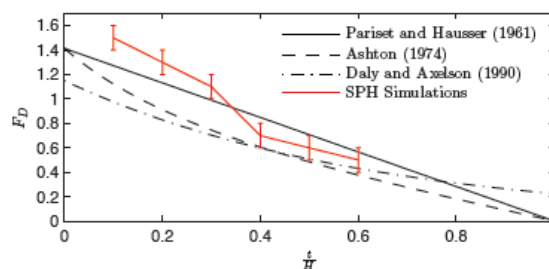


Figure 3 – Comparison of SPH results with theories. Top limit of error bar indicates the  $F_D$  at which overturning was observed. Bottom limit indicates the nearest simulation at a lower  $F_D$  at which there was no overturning. The critical value is between these two.

Ice jamming can cause an increase in forces exerted on hydraulic structures. Estimating these forces is of great interest to engineers. A coupled SPH-ALE discrete element model (DEM) is currently under development. Both sphere and circular disc shaped discrete elements are being considered. Figure 4 shows a 3D simulation of sphere shaped solids accumulating at an obstruction of narrowly spaced piers.

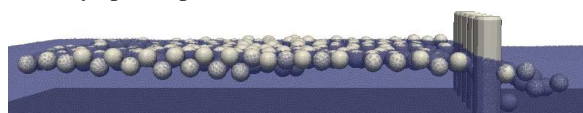
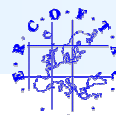


Figure 4 – Accumulation of solids upstream of piers.

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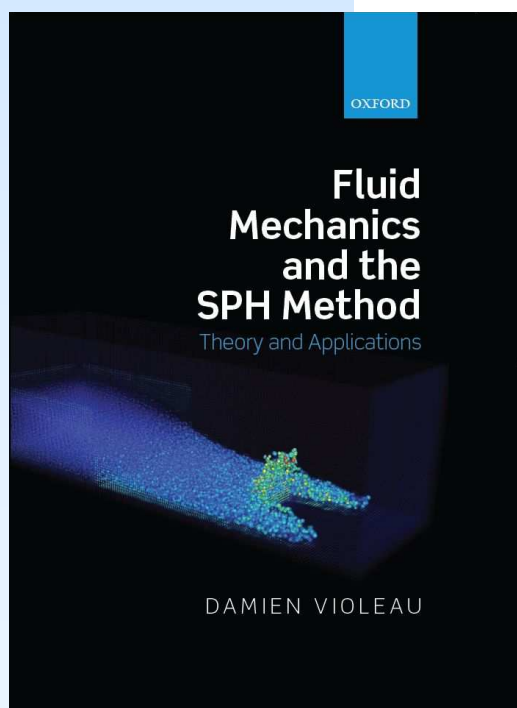


## A new book on Fluid mechanics and SPH

D. Violeau, EDF R&D, Chatou, France

This new book (Violeau, 2012) presents the SPH (Smoothed Particle Hydrodynamics) method for fluid modelling from a theoretical and applied viewpoint. It comprises two parts that refer to each other. The first part, dealing with the fundamentals of hydraulics, is based on the elementary principles of Lagrangian and Hamiltonian mechanics. The specific laws governing a system of macroscopic particles are built, before large systems involving dissipative processes are explained. The continua are discussed, and a fairly exhaustive account of turbulence is given. The second part discloses the bases of the SPH Lagrangian numerical method from the continuous equations, as well as from discrete variational principles, setting out the method's specific properties of conservativity and invariance. Various numerical schemes are compared, referring to the physics as dealt with in the first part. Applications to schematic instances are discussed, as well as practical applications to the dimensioning of coastal and fluvial structures.

Despite the rapid growth in the SPH field, this book is the first to present the method in a comprehensive way for fluids. It should serve as a rigorous introduction to SPH and a reference for fundamental mathematical fluid dynamics. This book is intended for scientists, doctoral students, teachers, and engineers who want to enjoy a rather unified approach to the theoretical basis of hydraulics or who want to improve their skills using the SPH method. It will inspire the reader with a feeling of unity, answering many questions without any detrimental formalism.



### Contents

#### Part I

**Chapter 1:** Lagrangian and Hamiltonian mechanics

**Chapter 2:** Statistical mechanics

**Chapter 3:** Continuous media and viscous fluids

**Chapter 4:** Turbulent flows

#### Part II

**Chapter 5:** Principles of the SPH method

**Chapter 6:** Advanced hydraulics with SPH

**Chapter 7:** SPH method validation

**Chapter 8:** SPH applied to hydraulic works

The book extends to 616 pages and comprises more than a hundred pictures. On-line purchase is available on the Oxford University Press website:

<http://ukcatalogue.oup.com/product/9780199655526.do>

'This is an unconventional, deep and broad-ranging treatment of mathematical fluid mechanics, leading to the development of SPH for complex engineering applications involving turbulent free-surface flow. The book is built on careful development of theory from Lagrangian, statistical and variational principles, underpinned by strong physical reasoning. For graduate students in engineering and physics, particularly those with an interest in SPH, this will be a valuable reference, and there are fresh insights for the most expert reader.'

Nathan Quinlan, School of Engineering and Informatics,  
National University of Ireland, Galway

'The book will serve as an invaluable guide and introduction to anyone interested in "how and why SPH works". This text will take them into the heart of the method to the most fundamental basic principles, and give them the definitive background on the technique. The book will be particularly useful for graduate research students and practising engineers. Furthermore, as SPH is now beginning to be part of university degree courses, this is possibly the only book that covers all the areas needed for further reading and study.'

Benedict Rogers, School of Mechanical, Aerospace and  
Civil Engineering, University of Manchester

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### References

Violeau, D., *Fluid Mechanics and the SPH Method. Theory and Applications*, Oxford Univ. Press, Oxford, 2012.