SPHERIC newsletter

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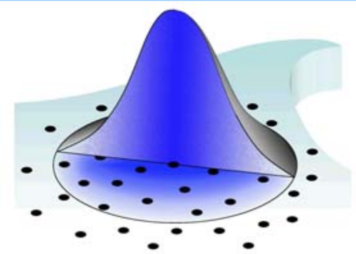
Contact: damien.violeau@edf.fr



Editorial

By ***David Le Touzé***
Chairman of the IVth SPHERIC workshop

The Fluid Mechanics Laboratory of Ecole Centrale Nantes (ECN) was very pleased to host the IVth international workshop of the SPHERIC community on its campus in Nantes, France. This fourth edition of the SPHERIC community workshop gathered 97 researchers, industry representatives and PhD students from 20 countries during 4 days, from May 26 to 29. This year again, the workshop led to very fruitful and constructive exchanges in a friendly atmosphere.

The increasing attendance of the workshop (+20%) and the 67 contributions received (+30%) confirmed the constant growth of interest in SPH worldwide. A wide range of topics were covered by the contributions, from numerical models to engineering applications, from physics to High-Performance Computing. And as every year since 2005, these contributions were of higher and higher quality.

The workshop began with a training day attended by more than 40 participants. After an introduction on the place of SPH in the simulation of engineering applications (D. Le Touzé, ECN, France), N. Quinlan (NUI Galway, Ireland) delivered a speech dedicated to the consistency, convergence and accuracy of the SPH spatial interpolation. The participants then trained on practical examples using the open-source code SPHysics, under the supervision of B. Rogers (University of Manchester, UK) and A. Crespo (University of Vigo, Spain). In the afternoon, J. Biddiscombe (CSCS, Switzerland) gave a lecture on the application ParaView-meshless developed at CSCS, dedicated to post-processing and visualization of meshless simulations. The attendees then trained on this application and discovered its recent developments.

Over the next three days, the 17 workshop sessions on various topics (see below) permitted to have a broad overview of the numerous SPH advances made in the last year. A brief opening speech was given by D. Violeau (EDF, France, Chairman of SPHERIC), and D. Le Touzé (ECN, France, Chairman of the IVth workshop). Three interesting keynote lectures on different aspects were also given: on astrophysics by Prof. W. Benz from University of Bern, Switzerland, on engineering applications by P. Cleary from CSIRO, Australia, and on structure and fluid-structure simulations by Prof. R. Vignjevic from Cranfield University, U.K. During the cocktail, the attendees could visit the large facilities of the Fluid Mechanics Laboratory of ECN, in particular a large wave tank and a medium-size towing tank. The next day, during the banquet, the Libersky student prize was awarded to Salvatore Marrone, from INSEAN, Italy for the best student paper and presentation. The participants were given colour paper proceedings.

The workshop success was also permitted by our generous sponsors: EDF (Electricité de France), DCNS (Naval Defence group), DGA (French Defence Ministry) and HydrOcean (spin-off of ECN). Fortunately, the weather kept nice, though windy, during the four days and permitted participants to discover the city center and the many rivers of Nantes. On behalf of all the Local Organization Committee colleagues, which I warmly thank for their help, we hope that all the attendees had an interesting and pleasant workshop in Nantes.

Contact: david.letouze@ec-nantes.fr

DAY 1: WEDNESDAY, MAY 27th, 2009

8:00	Registration and documentation	
8:45	Opening of the 4th SPHERIC Workshop	
9:00	**Keynote lecture: Prof. W. Benz, University of Bern, Switzerland**	
10:00	Coffee break	
10:20	**Session 1: Multi-fluids 1**	
11:20	**Session 2: Multi-fluids 2**	
12:20	Lunch	
14:00	**Session 3: Multi-fluids 3 and post-processing**	
15:15	**Session 4A: GPU & Astrophysics**	**Session 4B: Viscosity**
16:15	Coffee break	
16:30	**Session 5A: Fluids & Structure 1**	**Session 5B: SDPS & Sedimentation**
17:30	**Poster session**	
18:30	Welcome aperitif in hall A (building A)	

Keynote lecture: Prof. W. Benz, University of Bern, Switzerland
Cracking and crushing: Modeling the collisional history of small bodies in the solar system.

Session 1: Multi-fluids 1
***Chairman**: Andrea Colagrossi, INSEAN, Italy*

- *Hydrodynamic instabilities in compressible fluids using SPH*. Børve S., Price D.J.
- *Multiphase SPH: A new model based on acoustic Riemann solver*. Leduc J., Marongiu J.-C., Leboeuf F., Lance M., Parkinson E.
- *A conservative SPH method for interfacial flows with surfactant dynamics*. Adami S., Hu X.Y., Adams N.A.

Session 2: Multi-fluids 2
***Chairman**: Prof. Peter Stansby, University of Manchester, U.K.*

- *An SPH multiphase formulation with a surface tension model applied to oil-water separation*. Grenier N., Le Touzé D., Colagrossi A., Antuono M.
- *Comparison and evaluation of multi-phase and surface tension models*. Rogers B. D., Leduc J., Marongiu J.-C., Leboeuf F.
- Formulating surface tension with reproducing divergence approximation for multi-phase SPH. Hu X.Y., Adami S., Adams N.A.

Session 3: Multi-fluids 3 and post-processing

***Chairman**: Prof. Moncho Gomez Gesteira, University of Vigo, Spain*

- *SPH Van der Waals model for multiphase flows*. Tartakovsky A.M., Ferris K., Meakin P.
- *Specific pre/post treatments for 3-D SPH applications through massive HPC simulations*. Oger G., Leroy C., Jacquin E., Le Touzé D., Alessandrini B.
- *A fast algorithm for free-surface particle detection in 2D and 3D SPH methods*. Marrone S., Colagrossi A., Le Touzé D., Graziani G.

Session 4A: GPU & Astrophysics

***Chairman**: Prof. Willy Benz, University of Bern, Switzerland*

- *High Performance of SPH Codes: Best approaches for efficient parallelization on GPU computing*. Crespo A.J.C., Marongiu J.-C., Parkinson E., Gómez-Gesteira M., Dominguez J.M.
- *Modeling Water Waves in the Surf Zone with GPUSPHysics*. Hérault A., Vicari A., Del Negro C., Dalrymple R.A.
- *Influence of chemical reactions on gravitational fragmentation of gas-dust disc*. Stoyanovskaya O.P., Snytnikov V.N.

Session 4B: Viscosity

***Chairman**: Damien Violeau, Electricité de France*

- *SPH simulation of pulsatile flow inside of a cavity*. Shahriari S., Hassan I., Kadem L. (*cancelled*)
- *SPH viscoplastic fluid/solid simulation*. Tavares G.
- *SPH modelling of viscous and non-Newtonian sloshing*. Hughes J.P., James P.W., Carne C., Graham D.I.
- *SPH model for viscoelastic fluids with thermal fluctuations*. Vázquez-Quesada A., Ellero M., Español P.

Session 5A: Fluids & Structure 1

***Chairman**: Paul Groenenboom, ESI Group Netherlands*

- *Modelling impact on aerospace structures using the coupled FE-SPH approach*. Vignjevic R., Campbell J.C., Reed J.M.
- *High speed machining modelling: SPH method capabilities*. Limido J., Espinosa C., Salaün M., Mabru C., Chieragatti R.
- *On the concept of a hybrid particle method to model coastal bluff collapse during extreme events*. Vandamme J., Zou Q., Reeve D.

Session 5B: SDPD & Sedimentation

***Chairman**: Prof. Stefano Sibilla, University of Pavia, Italy*

- *Smoothed Dissipative Particle Dynamics model for colloidal particles in suspension*. Bian X., Ellero M.
- *Towards a resolution analysis in mesoscopic fluid flows using Smoothed Dissipative Particle Dynamics*. Vázquez-Quesada A., Ellero M., Español P.
- *Simulating rapid sediment scour by water flow with SPH*. Manenti S., Di Monaco A., Gallati M., Sibilla S., Agate G., Guandalini R., Maffio A.

Poster Session

- *Coastal flow simulation using SPH: Wave overtopping on an impermeable coastal structure*. Didier E., Neves M.G.
- *Improvements on SPH neighbor list*. Domínguez J.M., Crespo A.J.C., Gómez-Gesteira M.
- *Smoothed dissipative particle dynamics for the polymer in diluted solution*. Litvinov S., Ellero M., Hu X.Y, Adams N.A.
- *Remarks on FSI simulations using SPH*. Lobovsky L., Groenenboom P.H.L.
- *Graphics Processing Unit accelerated calculations of free surface flows using Smoothed Particle Hydrodynamics*. McCabe C., Causon D.M., Mingham C.G.
- *Two way Boussinesq-SPH hybrid model to study free surface waves*. Narayanaswamy M., Crespo A.J.C., Gómez-Gesteira M., Dalrymple R.A.
- *Massively-parallel SPH-simulations of viscous flows*. Ulrich C., Rung T.

- *Influence of the compressibility in Fluid-Structure interaction using Weakly Compressible SPH*. Viccione G., Bovolin V., Pugliese Carratelli E.

DAY 2: THURSDAY, JUNE 5th, 2008

9:00	**Keynote lecture: Dr. P. Cleary, CSIRO, Australia**	
10:00	Coffee break	
10:20	**Session 6: Boundary conditions 1**	
11:20	**Session 7: Viscosity & Turbulence**	
12:20	Lunch	
14:00	**Session 8: SPH-related particle methods**	
15:15	**Session 9A: : Boundary conditions 2**	**Session 9B: Sloshing**
16:15	Coffee break	
16:30	**Session 10A: Free-surface 1 & Parallel computing**	**Session 10B: ISPH**
17:30	Steering committee meeting	
19:15	Banquet and Libersky student prize	

Keynote lecture: Dr. P. Cleary, CSIRO, Australia
Large scale industrial and geophysical flow modeling.

Session 6: Boundary conditions 1
Chairman: *Nathan Quinlan, National University of Ireland, Galway*

- *Normal flux method at the boundary for SPH*. De Leffe M., Le Touzé D., Alessandrini B.
- *A 2D+t SPH model with enhanced solid boundary treatment*. Colagrossi A, Antuono M., Marrone S.
- *A semi-analytic approach for SPH modeling of solid boundaries*. Di Monaco A., Manenti S., Gallati M., Sibilla S., Agate G., Guandalini R., Maffio A.

Session 7: Viscosity & Turbulence
Chairman: *Prof. Francis Leboeuf, Ecole Centrale de Lyon, France*

- *Towards the simulation of wave-body interactions with SPH*. Cherfils J.-M., Blonce L., Pinon G., Rivoalen E.
- *Analysis of WCSPH laminar viscosity models*. González L. M., Sánchez J.M., Macià F., Souto-Iglesias A.
- *An SPH turbulence model*. Monaghan J. J.

Session 8: SPH-related particle methods
Chairman: *Prof. Robert Dalrymple, Johns Hopkins University, USA*

- *Incompressible moving boundary flows with the Finite Volume Particle Method*. Nestor R.M., Quinlan N.J.
- *Incompressible Finite Pointset Method for free surface flow*. Vacondio R., Mignosa P.
- *A particle based model to simulate plant cells dynamics*. Van Liedekerke P., Tijskens E., Ramon H., Ghysels P., Samaey G., Roose D.

Session 9A: Boundary conditions 2
Chairman: *Jean-Christophe Marongiu, Andritz Hydro, Switzerland*

- *SPH boundary forces*. Monaghan J.J., Kajtar J.B.
- *About compressible treatment and solid boundary conditions aspects of Smoothed Particle Hydrodynamics*. Blacodon Y., Bohbot J.
- *Inlet-outlet boundary conditions and truly incompressible SPH*. Ramos-Becerra G., Moulinec C., Emerson D.R., Gu X.J.

Session 9B: Sloshing
Chairman: *Antonio Souto Iglesias, Technical University of Madrid, Spain*

- *A study of sloshing absorber geometry for structural control with SPH*. Marsh A., Prakash M., Semercigil S.E., Turan Ö.F.
- *Using SPH in a co-simulation approach to simulate sloshing in tank vehicles*. Lehnart A., Fleissner F., Eberhard P.
- *Fuel loads in large civil airplanes*. Gambioli F.

Session 10A: Free-surface 1 & Parallel computing
***Chairman**: Benedict Rogers, University of Manchester, U.K.*

- *Laboratory experiments and SPH modelling of hydraulic jumps*. De Padova D., Mossa M., Sibilla S.
- *Flow modelling in the injector of a Pelton turbine*. Koukouvinis P.K., Anagnostopoulos J.S., Papantonis D.E.
- *Simulation of SPHERIC Benchmark Test 2, "3D schematic dam break and evolution of the free surface", by an improved parallelized particle method and SPHysics*. Gotoh H., Khayyer A., Ikari H. (*cancelled*).

Session 10B: ISPH
***Chairman**: Xiangyu Hu, Technical University of Munich, Germany*

- *Assessment of incompressible and weakly compressible SPH for marine applications*. Shipilova O., Bøckmann A., Skeie G., Bergan P.
- *A stabilised incompressible SPH based on the Projection Method*. Xu R., Stansby P., Laurence D.
- *An improved incompressible SPH method for wave impact simulations*. Khayyer A., Gotoh H., Shao S. (*cancelled*).

DAY 3: FRIDAY, JUNE 6th, 2008

9:00	**Keynote lecture: Prof. R. Vignjevic, Cranfield University, U.K.**
10:00	Coffee break
10:20	**Session 11: Fluids & Structure 2**
11:20	**Session 12: Fluids & Structure 3 & Stabilization models**
12:20	Lunch
14:00	**Session 13: Free-surface 2**
15:00	End of the workshop

Keynote lecture: Prof. R. Vignjevic, Cranfield University, U.K.
Development of SPH methods at Cranfield University.

Session 11: Fluids & Structure 2
***Chairman**: Paul Cleary, CSIRO, Australia*

- *SPH formulation with Lagrangian Eulerian adaptive kernel*. Lacome J.-L., Limido J., Espinosa C.
- *Artificial stress effects on structural dynamics using SPH*. Groenenboom P.H.L., Lobovsky L.
- *Modelling extreme wave loading of offshore structures*. Campbell J.C., Vignjevic R.

Session 12: Fluids & Structure 3 & Stabilization models
***Chairman**: Prof. Rade Vignjevic, Cranfield University., U.K.*

- *Simulations of complex hydro-elastic problems using the parallel SPH model SPH-Flow*. Oger G., Jacquin E., Guilcher P.-M., Brosset L., Deuff J.-B., Le Touzé D., Alessandrini B.
- *Numerical corrections based on diffusive terms for SPH schemes*. Antuono M., Colagrossi A., Molteni D.
- *Low Mach number numerical schemes for the SPH-ALE method. Application in free surface flows in Pelton turbines*. Marongiu J.-C., Leboeuf F., Caro J., Parkinson E.

Session 13: Free-surface 2
***Chairman**: David Graham, University of Plymouth, U.K.*

- *Simulating a real dam spillway flow with 3-D SPH*. Lee E.-S., Violeau D., Issa R., Ploix S., Marc R.
- *SPH for free-surface flow around a heaving oscillating cylinder using variable particle mass distributions: 2-D investigations*. Omidvar P., Stansby P.K., Rogers B.D.
- *Levee breaching with GPU-SPHysics code*. Dalrymple R.A., Hérault A.

Surface Tension in SPH models at SPHERIC 2009

B. D. Rogers, *School of Mechanical, Aerospace & Civil Eng., University of Manchester, U.K.*

Each year at the SPHERIC workshops, when the papers are presented and the discussion and Q&A sessions take place, several issues arise that are of importance and become hot topics. For example in the previous year at the 3rd SPHERIC workshop in Lausanne this topic was GPUs. This year on the first day of the 4th SPHERIC workshop, the issue that attracted much thought provoking discussion was surface tension.

Surface Tension is an area that has been investigated using SPH before such as in the work of Morris (2000), Monaghan (1995) and Hu *et al*. (2006). Even though SPH was invented in the 1970s surface tension is not a topic that has been investigated in depth. This year, this topic came to the fore of everyone's attention with five papers. The need to understand how well the phenomenon of surface tension is represented in SPH is driven by the fact that SPH is beginning to be used to simulate applications that require not only a multi-phase formulation but also an accurate formulation of surface tension. These problems include the rise of bubbles in columns, highly aerated flows in the surf zone where surface waves are breaking and impacting structures, highly violent flows in Pelton turbines and multi-phase flows through porous media.

This year, there were several presentations that looked in detail at surface tension. The first of these papers was by Leduc *et al*. (2009) who first presented a new approach for multi-phase flows using an acoustic Riemann solver in the context of an arbitrary Lagrange Euler (ALE)-based formulation. Their work is driven by the objective of understanding the role of surface tension on the surface of the impinging jets in Pelton turbines and how modelling this can lead to an improved understanding and possible improvement in the turbines' performance. Leduc *et al*. showed that their model could deal with a variety of flows such as dam breaks, etc. With relevance to surface tension, Leduc *et al*. presented a new model for surface tension that considers the internal molecular-like forces within each phase.

The second of the papers looking at multi-phase simulations and surface tension was presented by Grenier *et al*. (2009) who also presented an ALE-based formulation and simulated surface tension using an approach called continuum surface stress (similar to the continuum surface force explained later). Results with promising agreement were presented including a bubble rising in a column and the coalescing and splitting of multiple oil-oil bubbles.

The third of the interesting papers was presented by Rogers *et al*. (2009) who presented a comparison of different multi-phase models including classical variational SPH approach based on Colagrossi & Landrini (2003), the volume-fraction technique of Grenier *et al*. (2008) and the new model of Leduc *et al*. (2009). This paper then focussed on one particular surface tension case to compare how the different surface tension models of Morris (2000), Monaghan (1995) and Hu *et al*. (2006) perform within each multi-phase model.

The fourth of the papers to look at surface tension was by Hu *et al*. (2009) who used a reproducing divergence approximation and modified the colour gradient summations with a density weighting as part of their methodology.

Finally, the last paper to present a surface tension model was by shown by Tartakovsky *et al*. (2009) where a different approach to model the surface is achieved by means of a technique based on van der Waals forces.

Much of the discussion of the surface tension models focussed on three things (i) methodology, (ii) validation with an analytical solution and (iii) parasitic currents.

Methodology

With the exception of Tartakovsky *et al*. (2009) and Leduc *et al*. (2009), the main approach to model surface tension in many computational fluid dynamics (CFD) scheme uses the Continuum Surface Force (CSF) technique first presented by Brackbill *et al*. (1992). In this method the surface force which acts over the interfacial area is replaced by a volume force which acts over a very thin volume either side of the interface. For example, using the Young-Laplace law the momentum equation including surface tension is written as

$$\frac{\mathrm{d}\,\mathbf{v}_i}{\mathrm{d}t} = \frac{1}{\rho}\sigma\kappa\mathbf{n} = -\frac{1}{\rho}\sigma(\nabla\cdot\mathbf{n})\mathbf{n}$$

where σ is the surface tension coefficient, $\kappa = -\nabla\cdot\mathbf{n}$ is the surface curvature and $\mathbf{n}$ is the unit normal to the surface.

Evaluation of this force requires the estimation of the curvature of the surface. The method originally proposed by Brackbill *et al*. and used in various modified forms uses a colour function where each phase is assigned a discrete value. Gradients of these colour functions are then used to provide an estimate of the curvature. There are various ways this can be accomplished as presented by Morris (2000), Monaghan (1995) and Hu *et al*. (2006). However, there is no clear method which is better than any other. Both the methods of Leduc *et al*. (2009) and Tartakovsky *et al*. do not use the CSF method. While accurate as discussed below, the methods such as that of Leduc *et al*. (2009) are not strictly conservative since they do not include all the particle interactions within a kernel that straddles the surface interface.

Validation

As with all numerical models, some form of validation is essential. Many of the methods for surface tension use the equilibrium of forces at the interface using the Young-Laplace theorem to derive a surface tension force which itself leads to an analytical solution for the pressure drop across the interface of a static and stationary bubble or drop where one fluid is separated from another fluid by an interface of a given surface tension as shown in Figure 1.

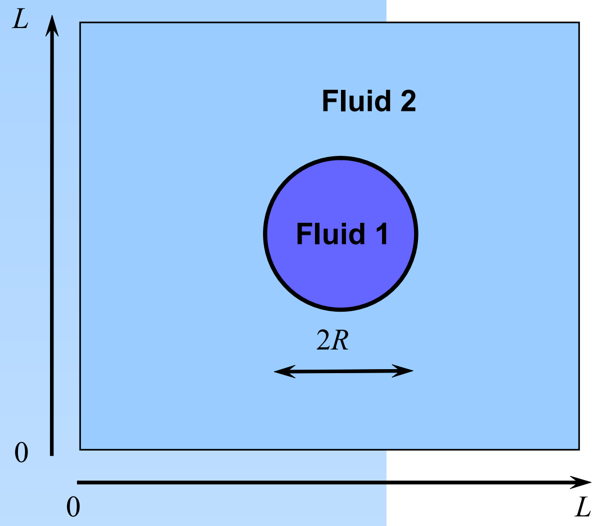


Figure 1 – 2-D Surface tension cases. Definition sketch.

This case has been used extensively in other CFD methods for validation of the static drop. Another test case with an analytical solution is an oscillating bubble which is a dynamic test case and therefore has an added level of complexity. All the techniques presented at the 4th SPHERIC workshop looked at either one or both of these validation cases. Below we can see some sample results presented. In Figure 2, we see the results from Hu *et al*. (2009) with their new surface tension model as applied to the static drop which shows good agreement with the classic pressure drop predicted by theory.

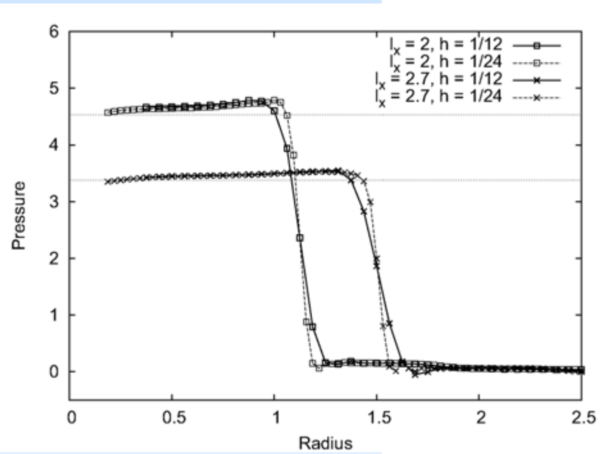
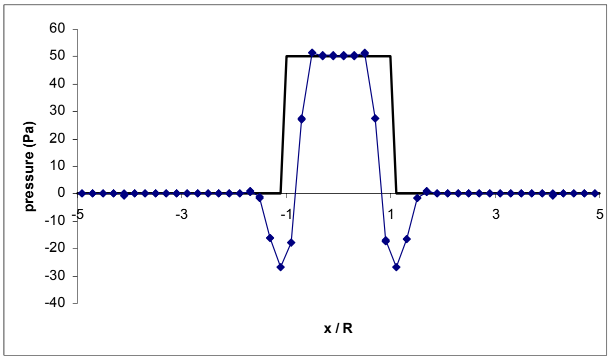
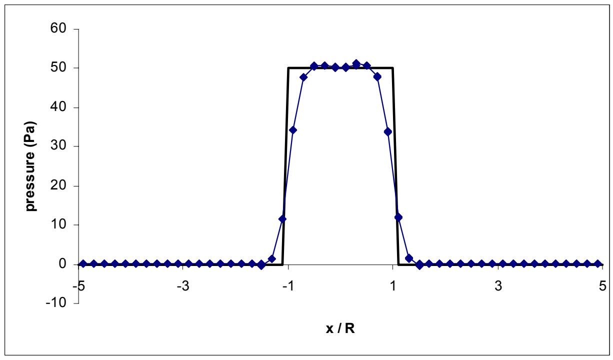


Figure 2 – 2-D Surface tension cases. Pressure profiles from Hu *et al*. (2009), their Figure 4a.

Similar results are given by Rogers *et al*. (2009) when comparing the different surface tension models as shown in Figure 3. As repeated here in this article, Rogers *et al*. demonstrated that the pressure profiles generated by the original model of Hu and Adams (2006) generate incorrect pressure profiles in the vicinity of the interface.



(a) Volume fraction formulation with *unmodified* HA06 surface tension model.



(b) Volume fraction formulation with *modified* HA06 surface tension model.

Figure 3 – 2-D Surface tension cases. Pressure profiles for Hu and Adams (2006) surface tension formulation in volume fraction ALE (Rogers *et al*. 2009, Figure 6).

In Figure 4, we see the results of Leduc *et al*. (2009) whith their new surface tension model which incorporates a local Laplace pressure correction (LLPC) along the CSF force. The new LLPC technique has produced good agreement for the pressure profile for the same case investigated by Rogers *et al*. (2009). As shown Leduc *et al*. also investigated the effect of using the theoretical curvature to help develop and verify their model. Finally, in Figure 5 we see the results presented by Tartakovsky *et al*. (2009) where the Van der Waals approach also showed good agreement for the pressure drop for several different values of curvature.

Parasitic currents

Finally a topic that was touched upon briefly in the paper of Rogers *et al*. (2009) and the presentation of Grenier was parasitic currents which are unphysical velocities produced by the surface tension model in the vicinity of the interface. Rogers *et al*. (2009) demonstrated that the choice of surface tension model and also the choice of underlying multi-phase SPH model could significantly affect the results. An example of the parasitic velocities generated is shown in Figure 6.

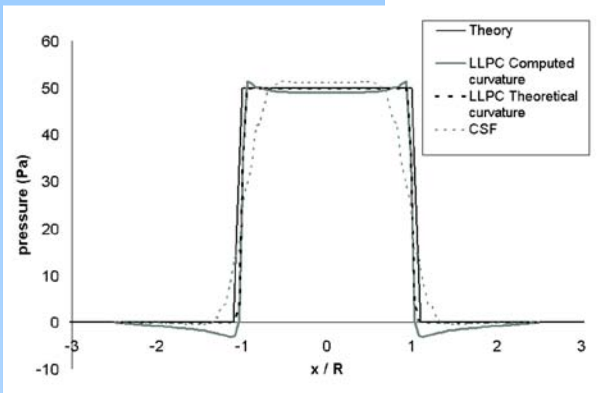


Figure 4 – 2-D Surface tension cases. Pressure profiles from Leduc *et al*. (2009), their Figure 6.

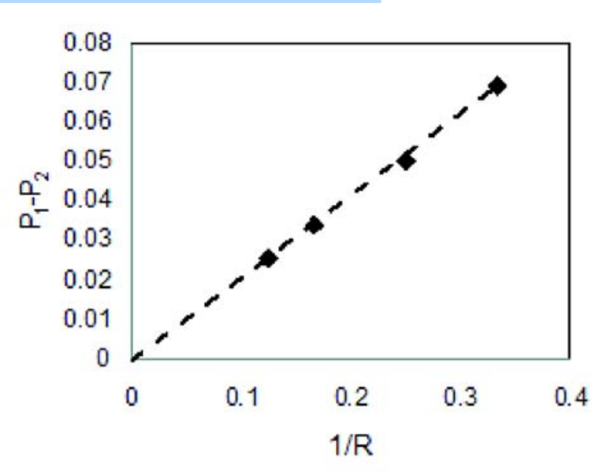


Figure 5 – 2-D Surface tension cases. Pressure differences from Tartakovsky *et al*. (2009), their Figure. 1 (*R* is the bubble radius).

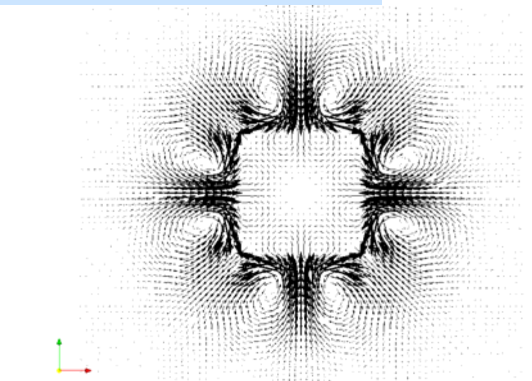


Figure 6 – 2-D Surface tension cases. Example parasitic velocities from Rogers *et al*. (2009).

Contact: benedict.rogers@manchester.ac.uk

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Note on the accuracy of SPH simulations of elastic plates during bending

***P. Groenenboom**, ESI Group Netherlands, Delft, The Netherlands*
***L. Lobovsky**, Department of Mechanics, University of West Bohemia, Pilsen, Czech Republic*

Gray, Monaghan and Swift (2001) demonstrated that artificial stresses can cure the tension instability of SPH, allowing simulation of elastic dynamics. They showed that the frequency of an oscillating plate obtained with SPH agrees with the theoretical values. There was, however, no mention about the force or stresses being correct. SPH with the artificial stress has subsequently been used to bending of a rubber plate in an example involving fluid-structure inter-action (Antoci *et al.*, 2007). Reasonable agreement could be obtained with the experimental data. Similar results were recently obtained with an independent code also using SPH for both water and rubber (Lobovský and Groenenboom). Since results obtained by one of the authors using the mixed FE-SPH approach for the same model showed significant differences that could not be attributed to the SPH model for the water or to fluid-structure interaction, elastic bending of a plate was investigated by both SPH and Finite Elements. For the test case the same geometry and elastic model of the rubber plate defined by Antoci *et al.* (2007) was used. The plate was constrained at one end and loaded by a uniform acceleration field increasing to a maximum level. The FE simulation was conducted with hexagonal elements in plane strain condition using 4 or 5 elements across the plate thickness; the displacements at the free end were indistinguishable. For the SPH simulations, the particle spacing *dp* (number of particles across the thickness) and the smoothing length *h* were varied. For a distribution of 8 particles across the width, the horizontal and vertical displacements of the free end are shown in figure 1 in comparison to the FE results.

It may be observed that the SPH results for the smaller *h* (*h*/*dp* = 1.02) agree rather well with the FE results; for *h*/*dp*= 1.13, the SPH results are somewhat higher. With 7 particles across (figure 2), the results differ dramatically. For *h*/*dp* = 1.02 the *x*-displacement is less than half that of the FE results, whereas for *h*/*dp* = 1.24, there are no oscillations left. For the smaller *h* the amplitude of the oscillation of the displacements increases after the load has become constant, which is even more pronounced with 5 particles across. Preliminary results from a systematic investigation of the displacements depending on *dp* and *h* indicate that the results for a small, odd number of particles across yield unrealistic results, whereas for a higher, even number of particles the results appear to converge slowly. These results were obtained using two independent SPH codes. It may be concluded that the utmost care has to be exercised for simulation of elastic bending with a limited number of particles across the thickness of the structure. Since it is not possible to make stable SPH simulations without the artificial stress, it is as yet unclear whether the poor results are due to this correction or to other causes. Without a solution to this problem, the finite element method remains the better option for bending simulations of thin structures.

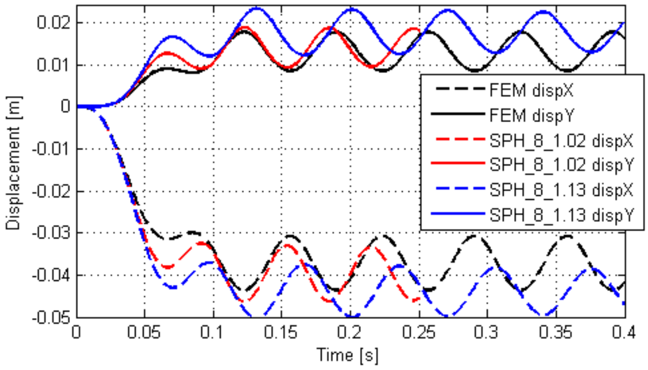

Figure 1 – Displacements of the free end for the SPH simulations with 8 particles across, and for FE (solid).

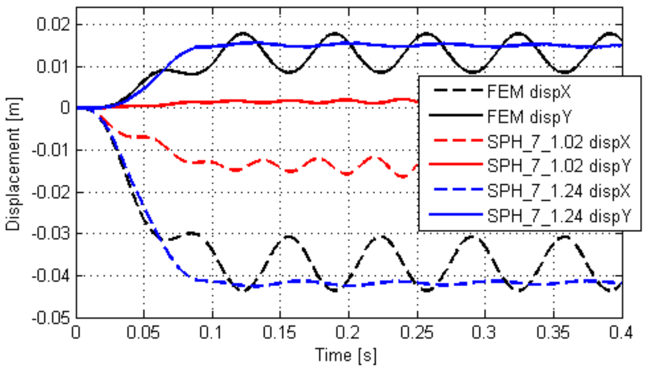

Figure 2 – Displacements of the free end for the SPH simulations with 7 particles across and for FE (solid).

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Contact: paul.groenenboom@esi-group.com

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The SPH Approach Applied to the Analysis of Water Impact

M. Anghileri & L.-M.L. Castelletti, *Politecnico di Milano, Dipartimento di Ingegneria Aerospaziale, Italy*

An accurate modelling of fluid/structure interaction is fundamental for the analysis of events critical for flight safety such as bird-strike, hail impact, water landing and fuel-tank crash behaviour. Since 2001, at the LAST Crash Lab of the Politecnico di Milano, coupled FE/SPH simulations of these events have been carried out using LSTC LS-Dyna (Hallquist, 2006). In 2003, the Politecnico di Milano joined a *Group for Aeronautical Research and Technology in Europe* (GARTEUR), the AG15, established for the improvement of SPH methods for applications to helicopter ditching.

In this framework, water impact drop tests were carried out using rigid and deformable structures. Rigid structures were used to evaluate assets and drawbacks of the code used for the simulations. Deformable structures were used to evaluate the reliability of numerical approach as a means to design water-impact safe structures. Simulations of the water impact of rigid bodies (figure 1) and deformable structures (figure 2) showed that the SPH method is a reliable numerical tool for the analysis of this event (Anghileri *et al*., 2007a, 2007b).

Impact loads during a ground impact and a water impact are rather different. Most of the devices developed to improve helicopter crashworthiness are designed for ground impacts and, therefore, may result useless during a water landing. Since a relevant number of accidents occurs on water, studies on water impact are justified. In analysing the water impact of a compliant structure not only the impact forces, but also the pressures are relevant. In fact, the pressures have a deep influence on the failure mechanism of the structure and, hence, the dynamics of the event.

Adopting the SPH approach, it could become extremely difficult to evaluate impact pressures with a degree of accuracy when the distance among the particles grows. An *acceptable* degree of accuracy can be obtained by increasing the number of particles. However, the larger the number of particles, the larger the required computational efforts and, therefore, dealing with unbounded domains, the computational efforts required by the SPH approach could become unaffordable even for the most recent high-performance super-computers. In addition, increasing the number of particles does not necessarily imply improving the accuracy of the simulation as instabilities may arise.

Another difficulty in evaluating impact pressures adopting the SPH approach is in the definition of the FE/SPH interface. Contact algorithms are widely used in commercially-available codes to couple the FE mesh and the SPH particles. Even if this approach is known to be in some respects incorrect, it appears that research aimed at improving the FE/SPH coupling has found no application in these codes.

In view of the abovementioned comments, it seems fundamental to establish *rules of thumb* as guidelines to create reliable numerical models and avoid inaccuracy. Accordingly, sensitivity analyses to locally increase the number of particles (although uniform patterns are usually recommended) and to improve the definition of the contact interface are generally recommendable.

Also, mixed FE/SPH models of the water region (where only the impact region is modelled using SPH) have shown to provide a way to obtain a good degree of accuracy without requiring large computational efforts.

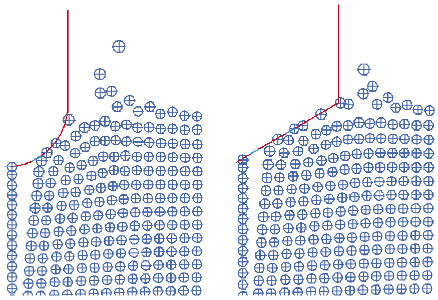

Figure 1 – Rigid body water impact.

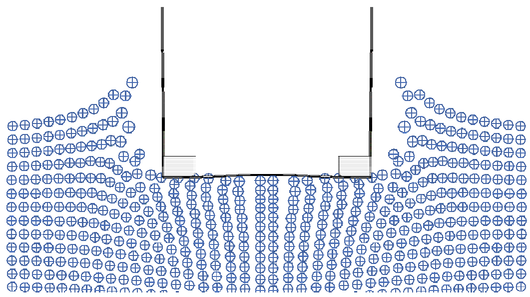

Figure 2 – Deformable body water impact.

Contact: luigi.castelletti@polimi.it

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