Développement d'un solveur de calcul non-linéaire sous CUDA

-

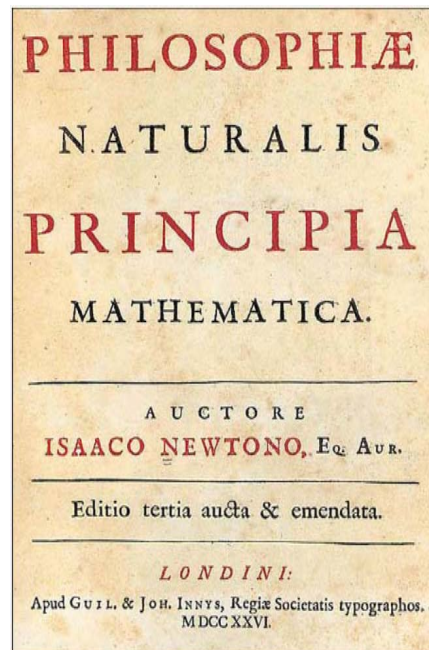# Transient dynamic code development with CUDA
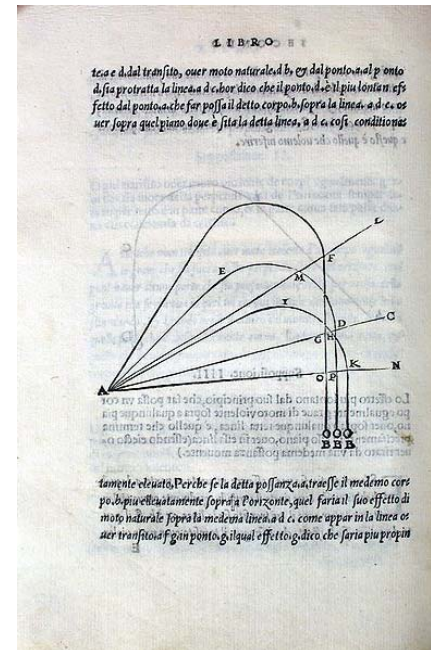
June 2011

Why IMPETUS ?

IMPETUS

Physical meaning: Rather vague form of momentum, impulse

As literary term: Driving force, stimulus

Newton refers to the quantity "impetus" in his work Principia Mathematica (1687)

Tartaglia ballistic curves (edited in 1606) based on impetus theory

Who are we ?

An **independent** specialist company network devoted to non-linear analysis
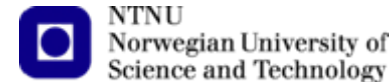
Who are we ?

- **8 engineers highly qualified:**

    - 5 Phd, 3 BsC

    - Mechanical Eng, Applied Math, Computer Sc, 2 experts in GPU computing

    More than 50 scientific articles in international journals with peer review (link)

- **Strong interactions with academic research**

- **Actual funded R&D projects:**

    -**FNS NextGenFSI** [sas IMPETUS Afea (France) - IMPETUS Afea as (Norway+Sweden)]
        Development of Next Generation of Fluid-Structure Interaction

    -**EPICEA Modcomp** [sas IMPETUS Afea (France) – ISAE]
        Strongly innovative modeling of composite crash and impact

Our philosophy

We want to offer an **accurate, general purpose, explicit solver** with as few parameters to tune as possible.

IMPETUS Afea Solver facts:

- Unique **accurate higher order solid elements** that can handle extremely large deformations (good for plasticity and bending, no hourglassing).

- Extremely powerful **particles methods** that can be used to model gas, high explosives, sand and fluids.

- **Massively parallel** new code that uses graphic cards (**GPU**) to accelerate calculations.

Our common goal

→ **To develop the Next Generation of Multi-Physics Simulation Tools**

Fast
Parallel Computing on Graphic
Processor Units (GPU)
Personal Supercomputer

Accurate
Unique Finite Element method
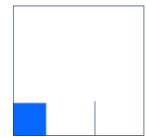Unique SPH method
Unique Blast Particle method

User-friendly
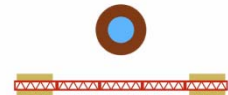Simplified keywords
Efficient Post-processor

Fluid-Structure interaction
Purely Lagrangian approach
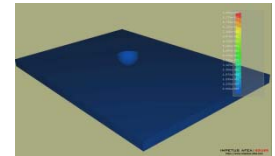SPH-FE coupling

Blast loading
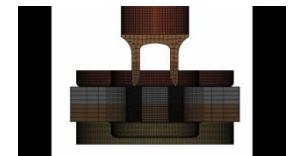Purely Lagrangian approach
Blast Particle - FE coupling

Composites impacts
Unique approach for delamination
Efficient material model

High deformation process
Unique Finite Element formulation
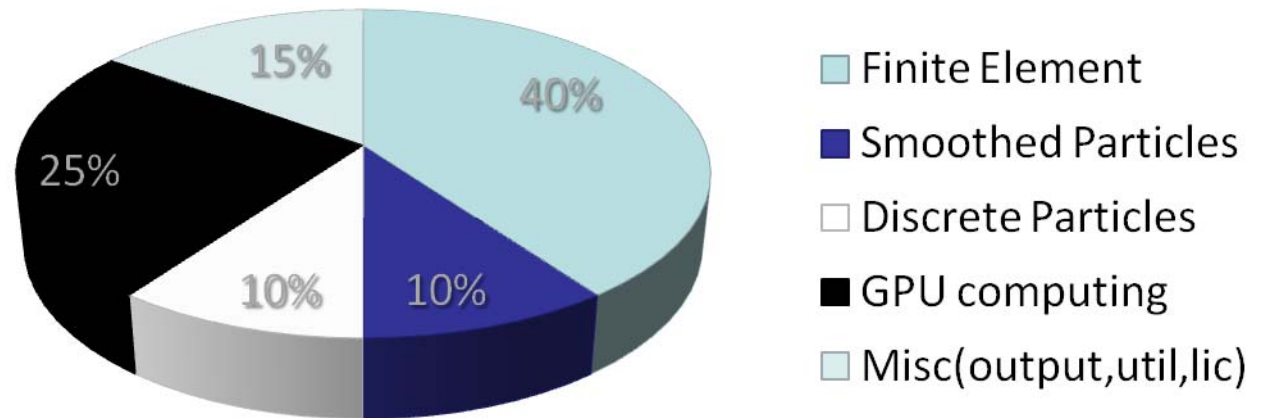

...

IMPETUS SOLVER ®

Code history

From scratch 2007

Code languages

Fortran
Cuda
C++

Code structure

- Finite Element — 40%
- Smoothed Particles — 10%
- Discrete Particles — 10%
- GPU computing — 25%
- Misc(output,util,lic) — 15%

IMPETUS SOLVER® | GPU code

Our feedback:

Particles methods very well suited for GPU

        - all particle methods are now on GPU

        - peak acceleration can reach 100x on simple (non industrial) cases

Finite element method more complex to port on GPU

        - most consuming parts are treated on GPU

        - classic FEM could be easier to port on GPU

Contact algorithm very complex to optimize on GPU

        - balance between computation time and
uniqueness of contact definition

        - current state : 50% CPU time spent in contacts !

General-purpose computing on graphics processing units (GPGPU)

Actual reached speed up performance

- **Full scale blast simulation (blast particles + FE) : 10X**

- **Full scale FSI simulation (SPH + FE) : 40x**

Speed up is not a goal **(80% of the time spent by an engineer is in pre-post processing phase)**

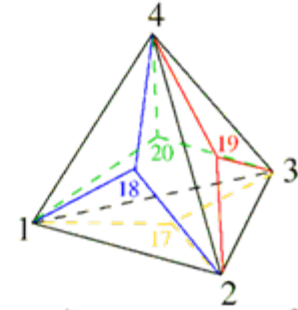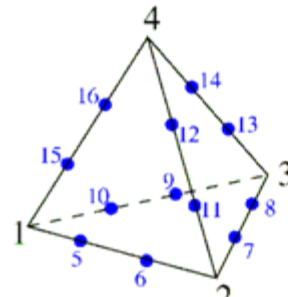**Speed up is a way to develop new methods**

Finite Element Method

**Unique accurate higher order solid elements
that can handle extremely large deformations**
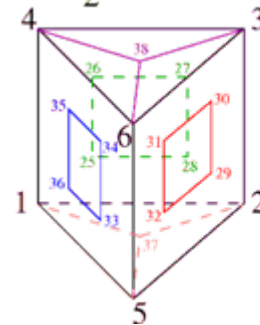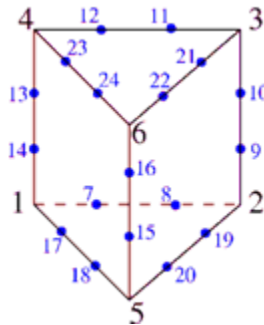
IMPETUS Afea proprietary method

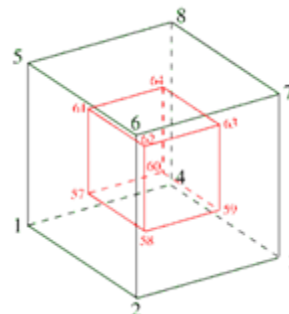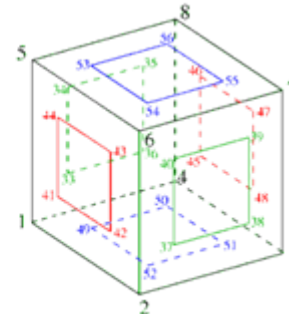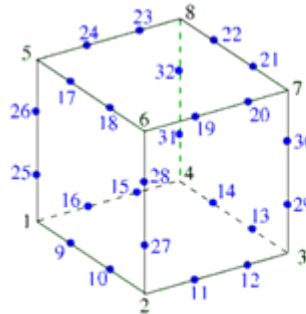**High order elements – Fully integrated**

Cubic 20-node tetrahedron
(good in plasticity)
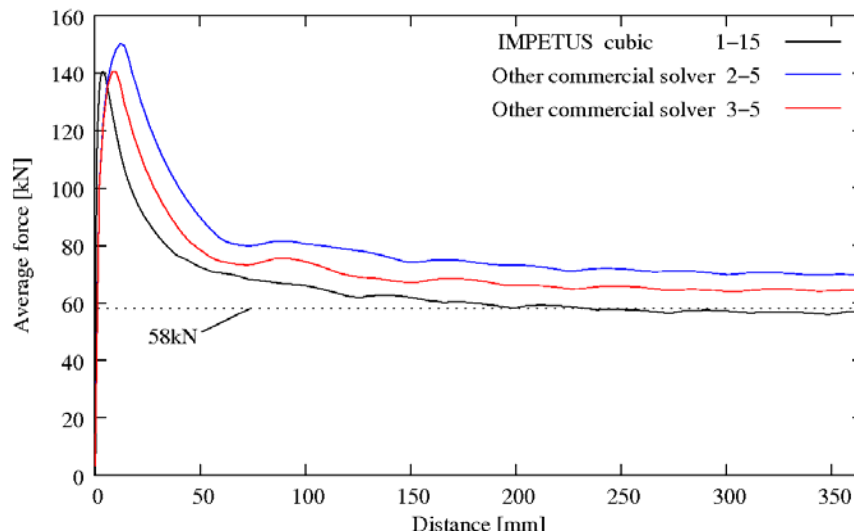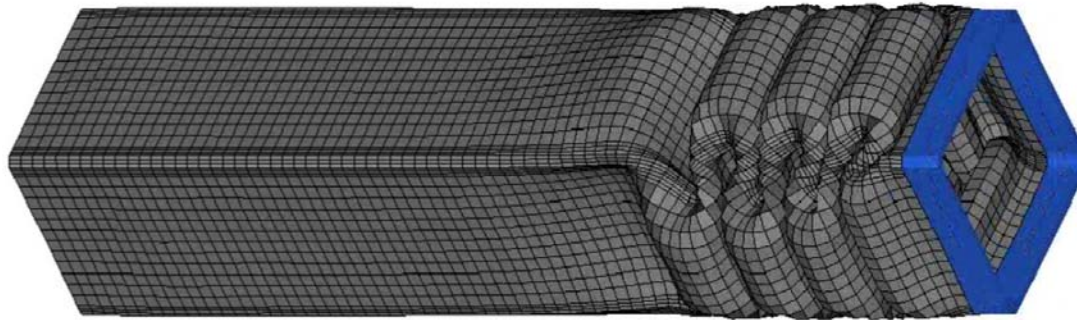
Cubic 40-node pentahedron
(good in plasticity)
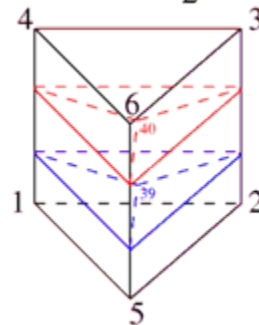
Cubic 64-node hexahedron
(excellent in plasticity)

Lower order elements are also available but our goal is Accuracy

IMPETUS Finite Elements – Good in bending

A cubic hexahedron has 4x4x4=64 nodes. These elements are good in bending.

Faster and more accurate !

A standard solid model with the same node spacing (3 elements across thickness and in-plane size 5 mm) and S/R integrated elements require 11h 19min on one CPU to complete 25 ms. The linear elements are too stiff in bending and the mean crush force obtained is 64 kN. A model with 2 elements across thickness and in-plane element size 5 mm needs 4h 42min on one CPU and gives a mean crush force of 70 kN.

Automotive Market

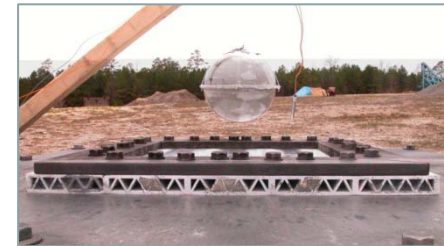## Car crash:

- Full solid elements model – no shell elements
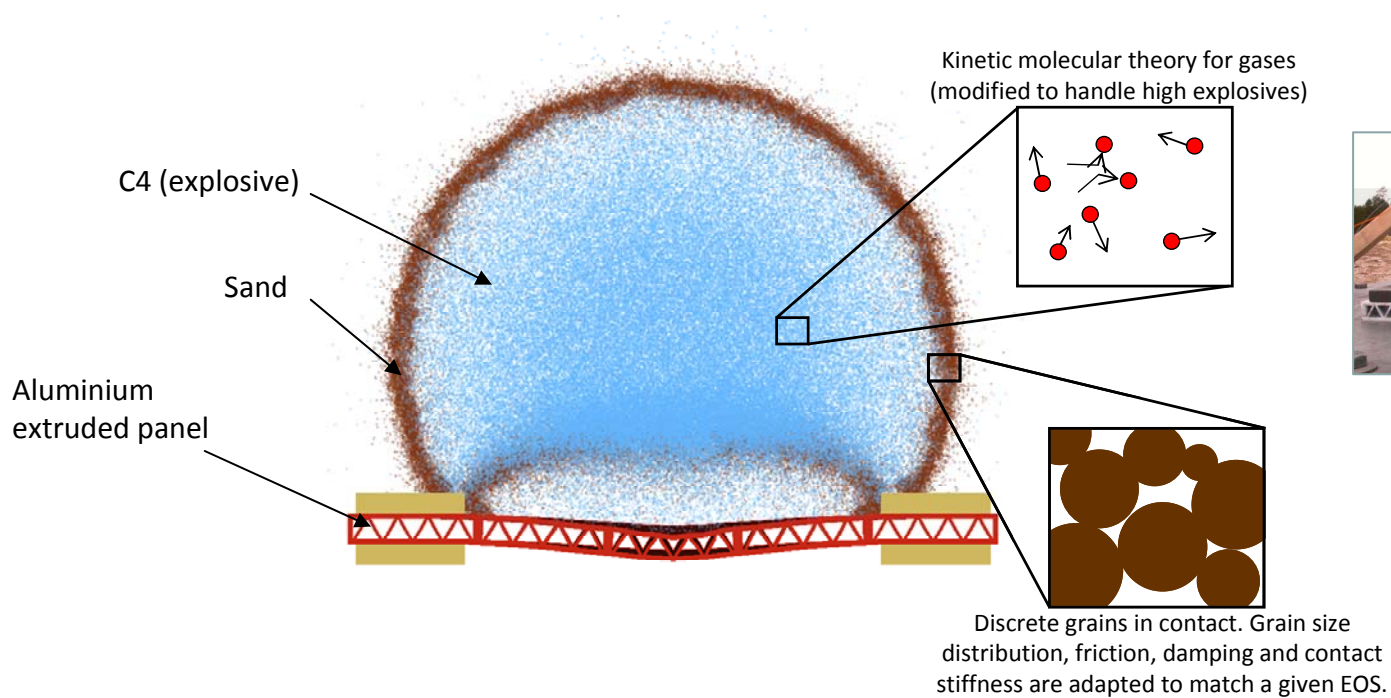
SPR crash box assembly:

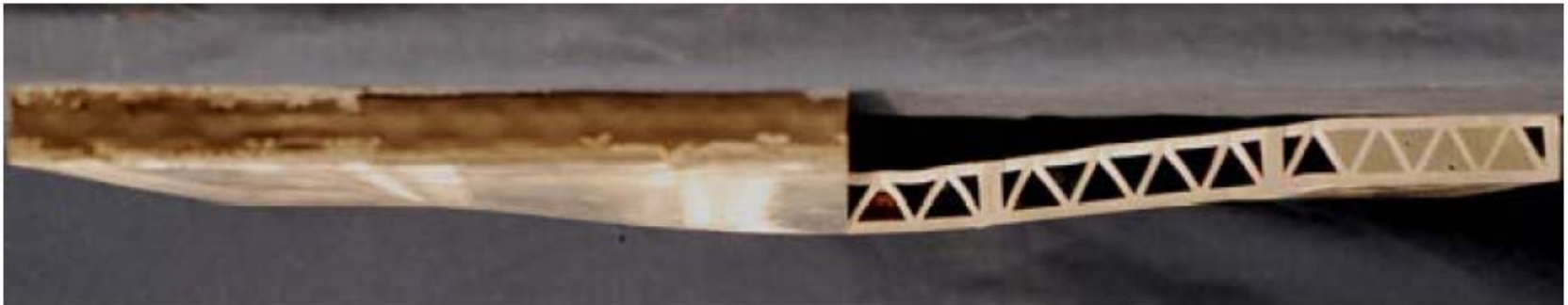- Our code can handle extreme deformation without remeshing

Particle Blast

IMPETUS Afea proprietary method

Kinetic molecular theory for gases
(modified to handle high explosives)

C4 (explosive)

Sand

Aluminium
extruded panel

Discrete grains in contact. Grain size
distribution, friction, damping and contact
stiffness are adapted to match a given EOS.

IMPETUS AFEA | SOLVER®

Particle blast - example
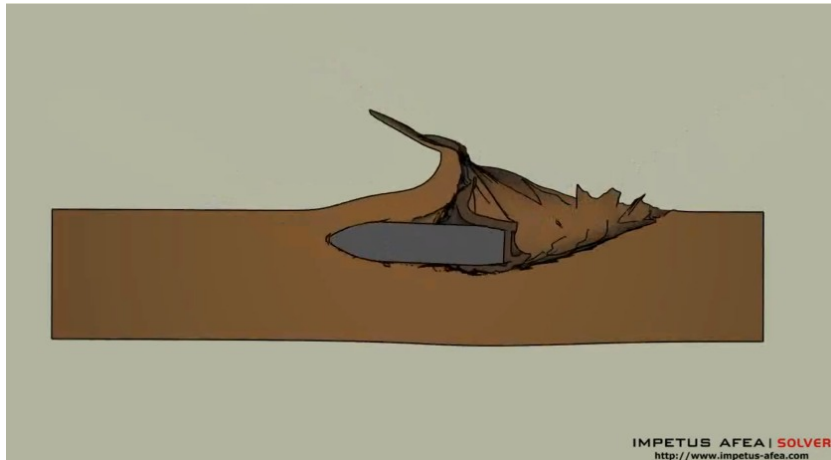
Deflection at stand-off distance 25cm

B dry sand

A saturated sand
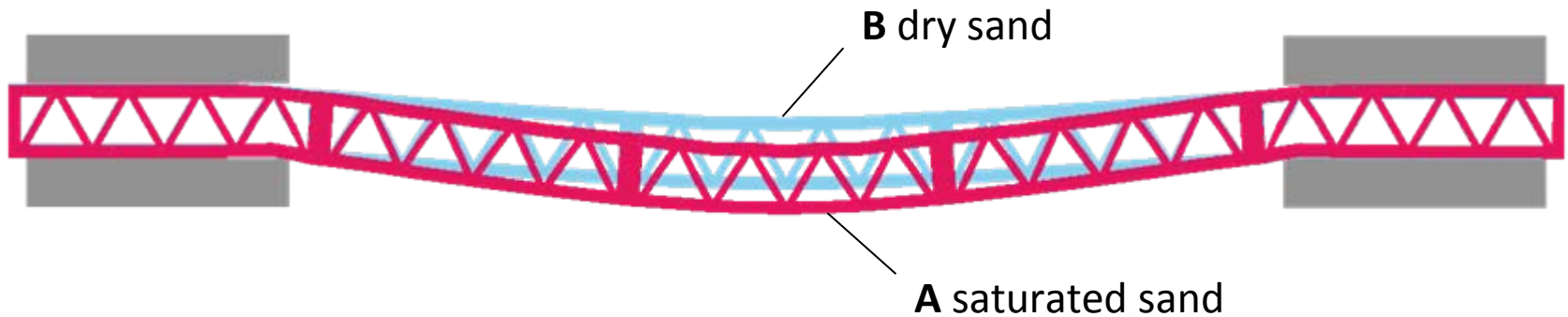
Experiment by Haydn Wadley at University of Virginia

Defense Market

Bullet perforation:

- Our unique FE formulation avoid remeshing needs

- Automatic FE to particles conversion avoid mass loss problems

Blast on complex structure:

- Purely lagrangian description that avoid classic ALE diffusion problems
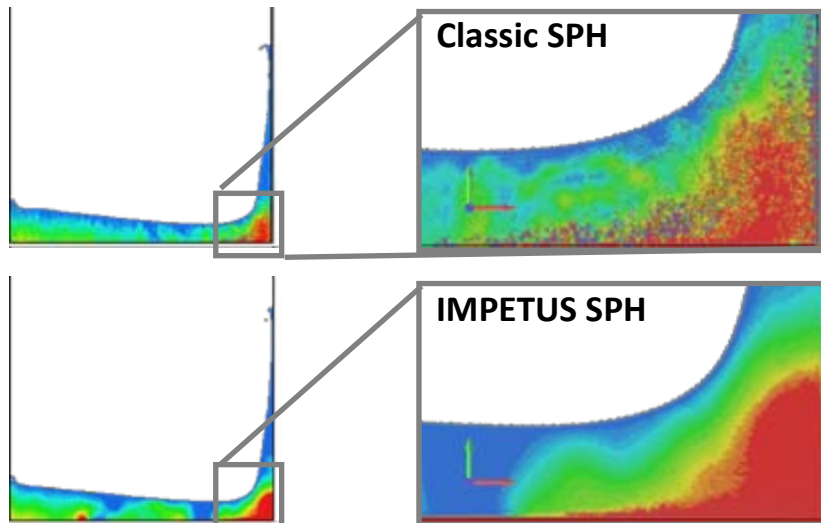
IMPETUS AFEA | SOLVER®
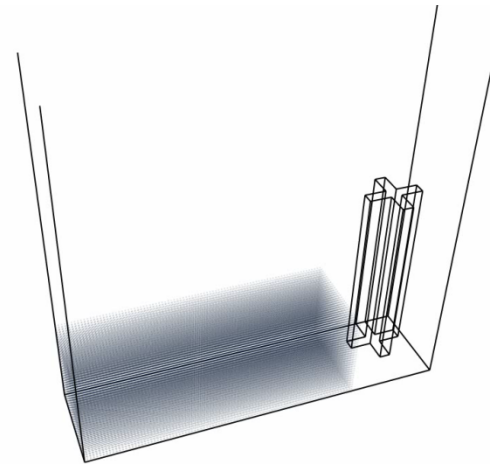
S.P.H.

IMPETUS Afea proprietary method

IMPETUS Smoothed Particle Hydrodynamics

Impetus-SPH facts:

▪Overcomes classical bad pressure field SPH evaluation

▪Allows larger time step

▪Well suited to violent water impacts

Mixing fluids
FE-SPH coupling

Dam break test (pressure field visualization)

IMPETUS New Meshless Fluid Dynamics Method

Impetus MFD facts:

- New numerical algorithm for Fluid Structure Interaction

- No artificial viscosity

- No tensile instability

- Hydraulic ram impact

- Large speed-up obtained using Graphic Processor Units (**40x**)

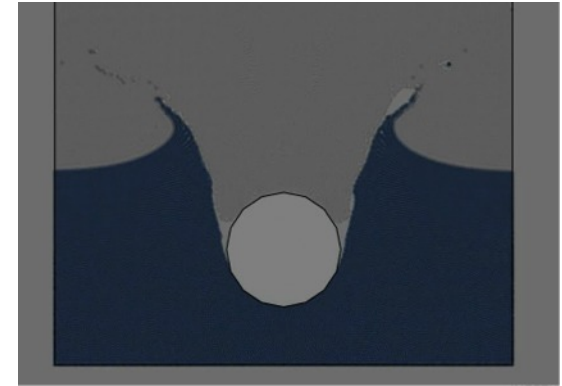- Full scale fluid structure interaction modeling now feasible
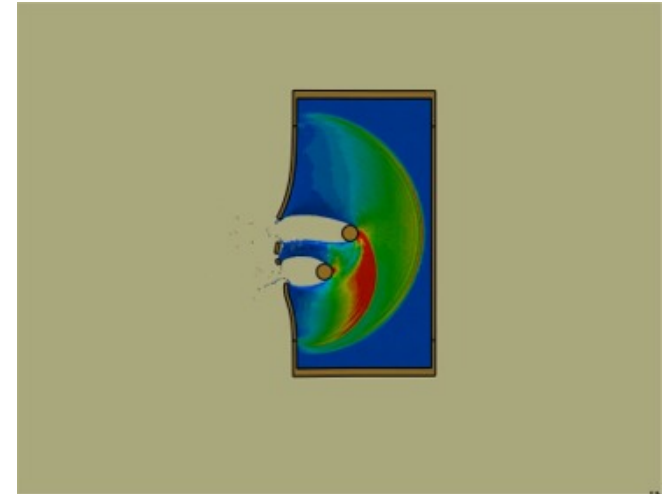
3D Hydraulic Ram **(~20,000,000 SPH elements)**

Future developments

Market strong demands:

- Bigger and bigger models → multi-GPU

- Visualization

- Complex mixing, phase transition → multi-phasic

- Air and Water blast → corpuscular/ISPH coupling

- Composites crash and impacts → multi-scale approach

These key aspects are linked to challenging R&D

Our R&D effort are currently supported by:

Website: www.impetus-afea.com

Mail: jll@impetus-afea.com