

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

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**Transient dynamic code development with CUDA**

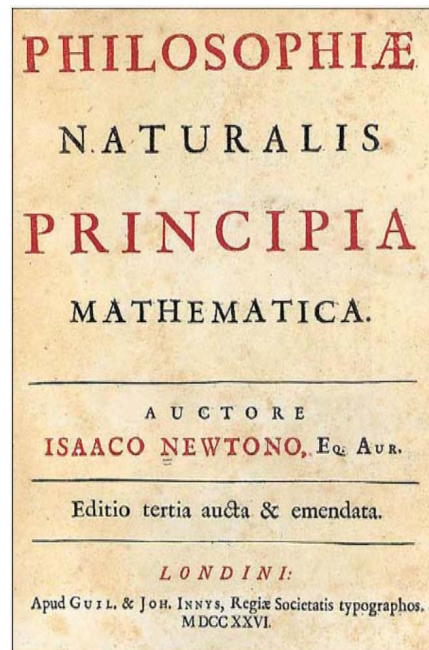
June 2011

# Why IMPETUS ?

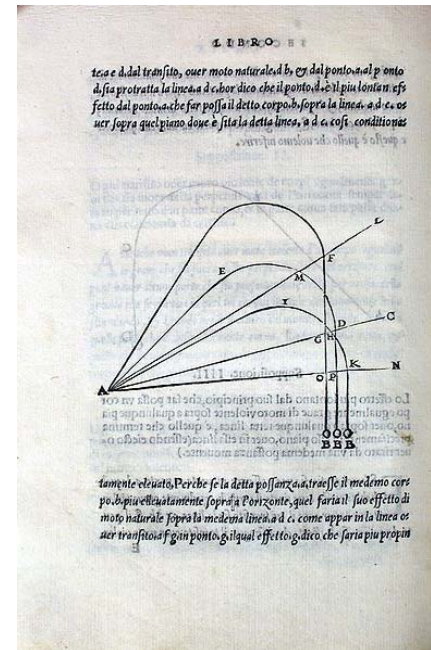
## IMPETUS

**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 ?

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An **independent** specialist company network devoted to non-linear analysis



# Who are we ?

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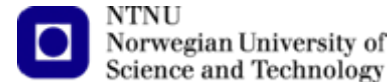
- **8 engineers highly qualified:**

- 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

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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

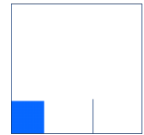
## User-friendly

Simplified keywords  
Efficient Post-processor



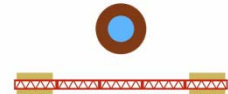
## Fluid-Structure interaction

Purely Lagrangian approach  
SPH-FE coupling



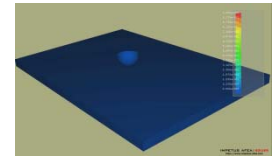
## Blast loading

Purely Lagrangian approach  
Blast Particle - FE coupling



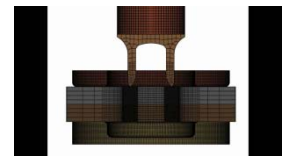
## Composites impacts

Unique approach for delamination  
Efficient material model



## High deformation process

Unique Finite Element formulation



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# IMPETUS SOLVER<sup>®</sup>

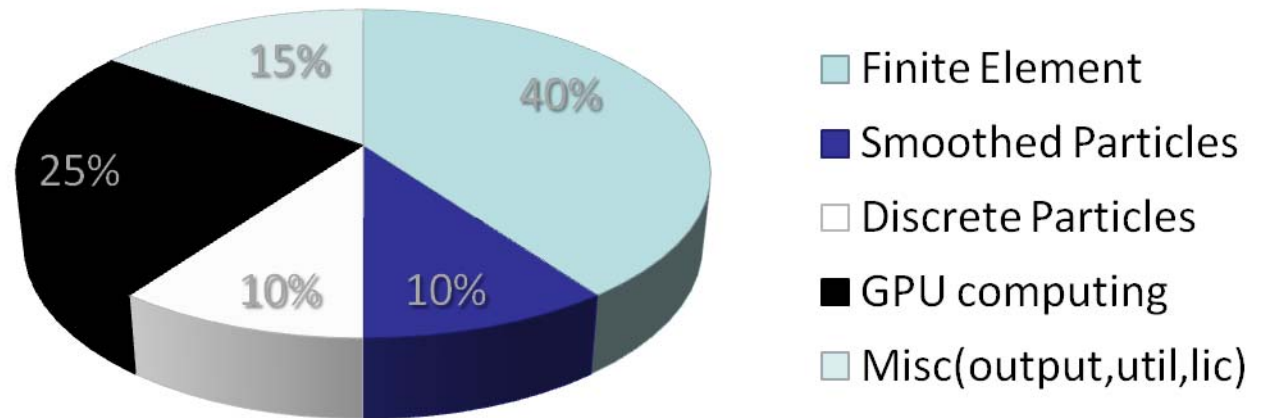
## Code history

From scratch 2007

## Code languages

Fortran  
Cuda  
C++

## Code structure



# IMPETUS SOLVER® | GPU code

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## 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

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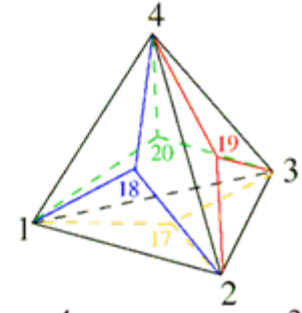
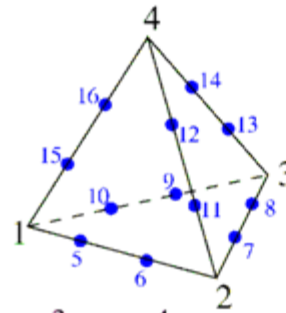
**Unique accurate higher order solid elements  
that can handle extremely large deformations**

**IMPETUS Afea proprietary method**

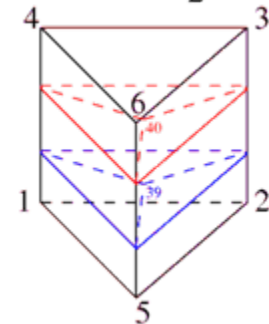
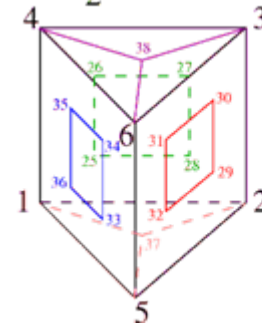
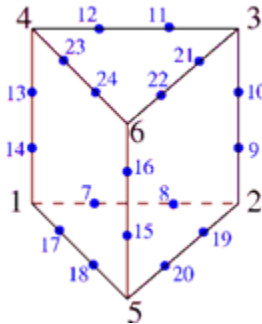
# IMPETUS Finite Elements - High order elements

## High order elements – Fully integrated

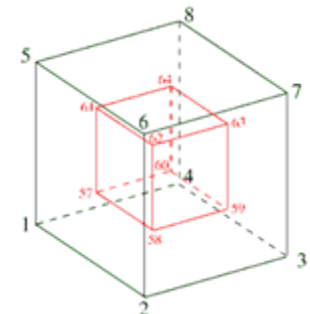
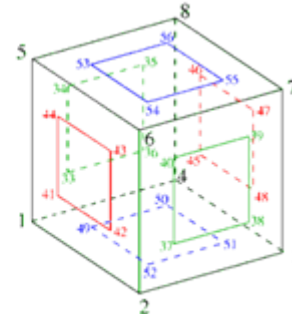
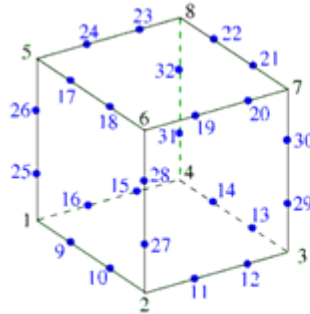
Cubic 20-node tetrahedron  
(good in plasticity)



Cubic 40-node pentahedron  
(good in plasticity)



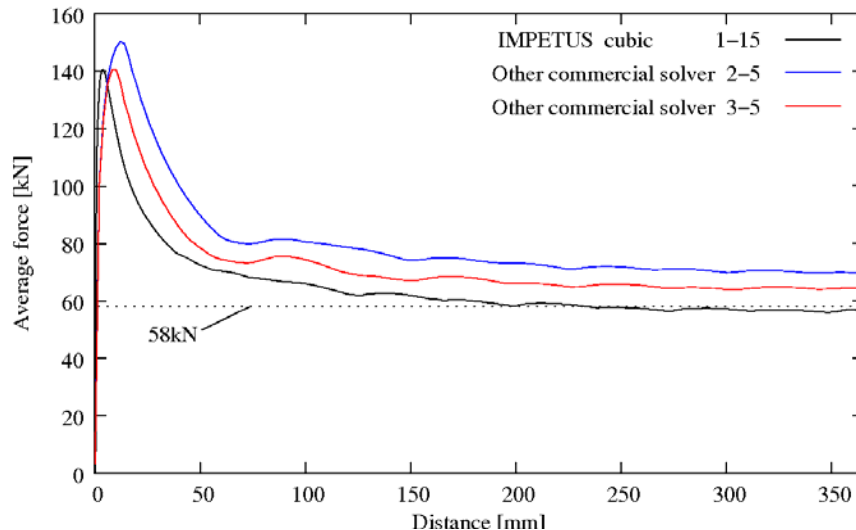
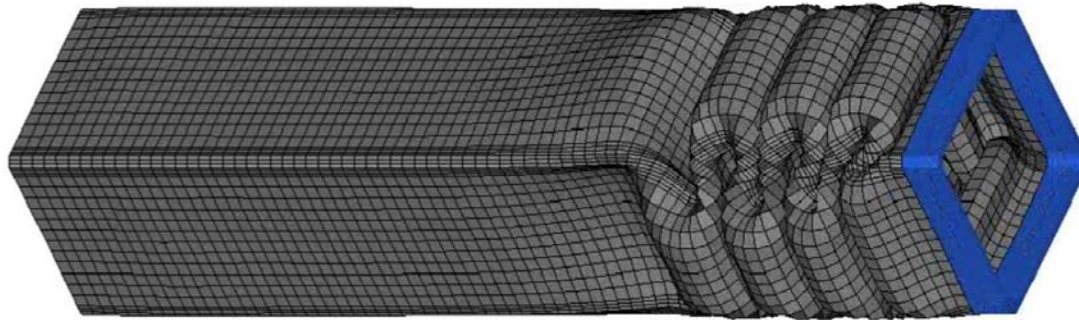
Cubic 64-node hexahedron  
(excellent in plasticity)



Lower order elements are also available but our goal is Accuracy

# IMPETUS Finite Elements – Good in bending

A cubic hexahedron has  $4 \times 4 \times 4 = 64$  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

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Car crash:

- Full solid elements model – no shell elements



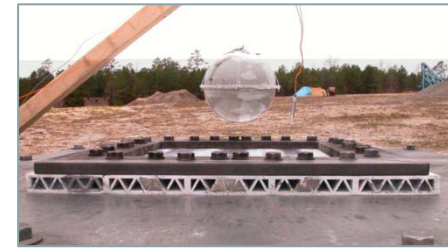
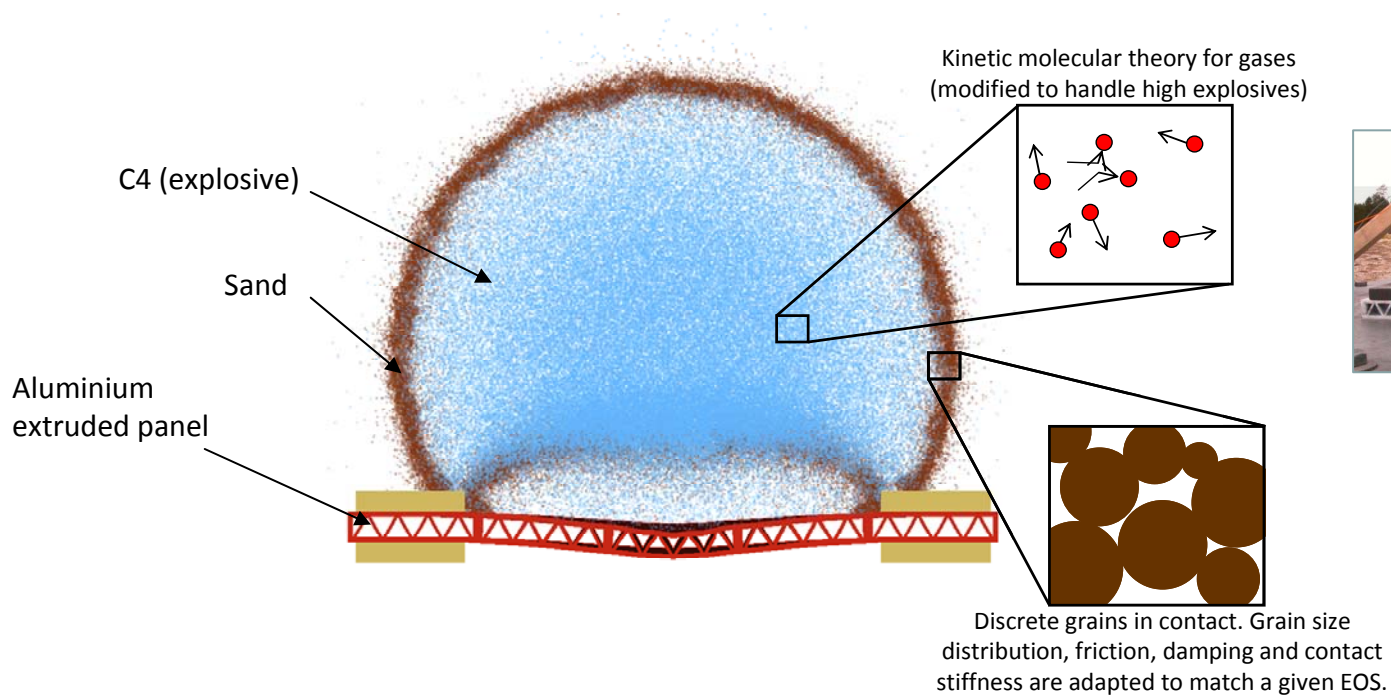
SPR crash box assembly:

- Our code can handle extreme deformation without remeshing

# Particle blast – simple example

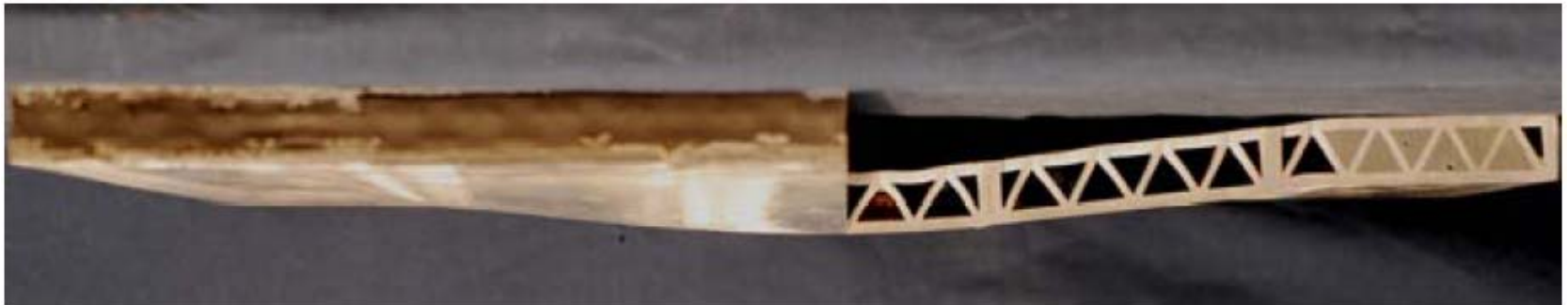
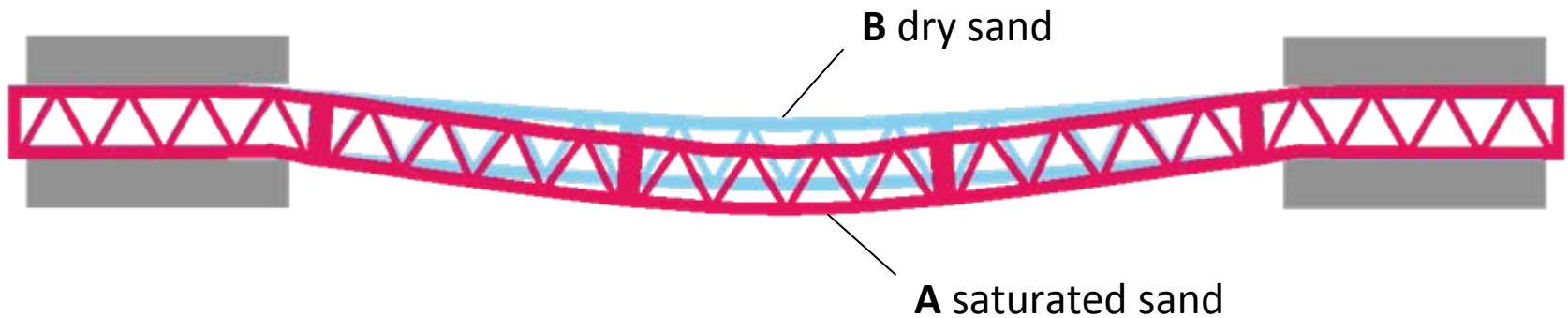
## Particle Blast

### IMPETUS Afea proprietary method



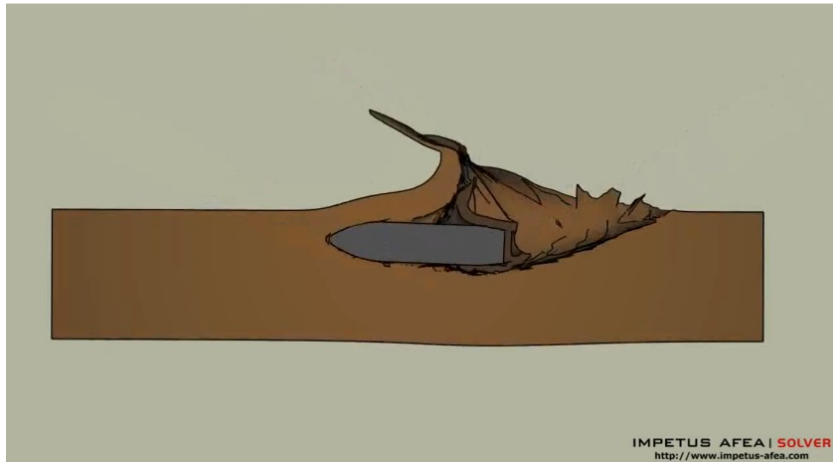
# Particle blast - example

Deflection at stand-off distance 25cm



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

# Smoothed Particle Hydrodynamics

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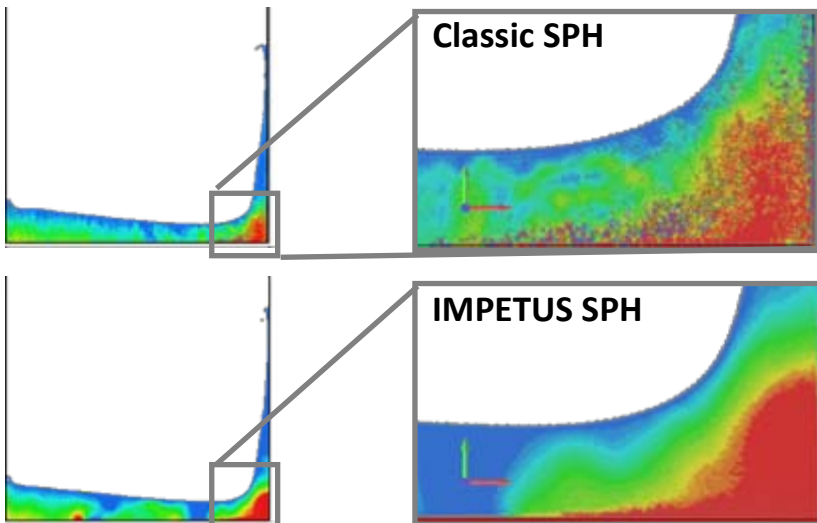
**S.P.H.**

**IMPETUS Afea proprietary method**

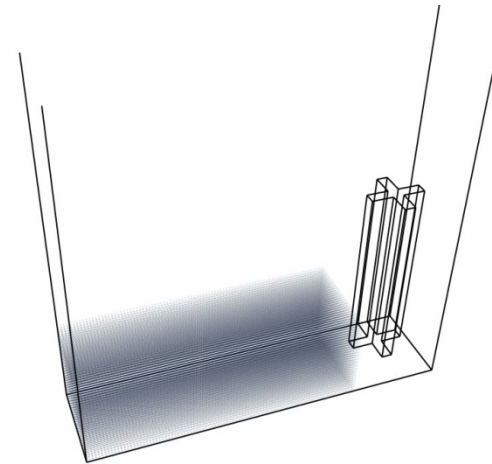
# IMPETUS Smoothed Particle Hydrodynamics

## Impetus-SPH facts:

- Overcomes classical bad pressure field SPH evaluation
- Allows larger time step
- Well suited to violent water impacts



Dam break test (pressure field visualization)



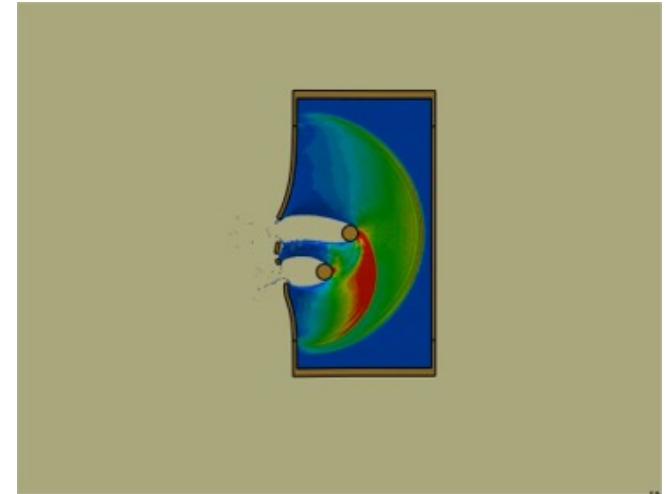
Mixing fluids  
FE-SPH coupling

IMPETUS AFEA | SOLVER  
<http://www.impetus-afea.com>

# 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

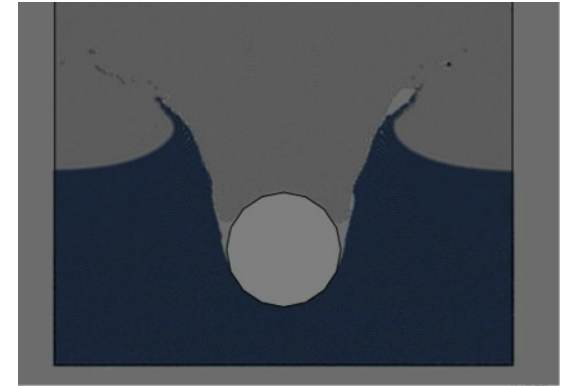


3D Hydraulic Ram (**~20,000,000 SPH elements**)

# 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:



# CONTACT

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