Application of SPH to solid mechanics problems

Tom De Vuyst
Rade Vignjevic
James Campbell
Nenad Djordjevic
Kevin Hughes

Overview

- Introduction/Motivation
- In-house SPH code overview
- Fluid-structure interaction
- Solid mechanics - examples
- Solid mechanics - current work

Introduction/Motivation

Introduction/Motivation

- Failure of materials and structures due to transient loading (e.g. impact, crash)
- Simulation tools are not always able to accurately predict behaviour
- SPH has attractive features:
  - Large deformations
  - Lagrangian
  - Treatment of fracture

In-house SPH code overview

In-house SPH code overview

Eulerian and Total Lagrangian kernel formulations

Constitutive models (elastic, elasto-plastic, composites)

Equations of state (Tait, Mie-gruneisen)

Boundary conditions (prescribed displacement, velocity, acceleration)

Body force

Multiple materials

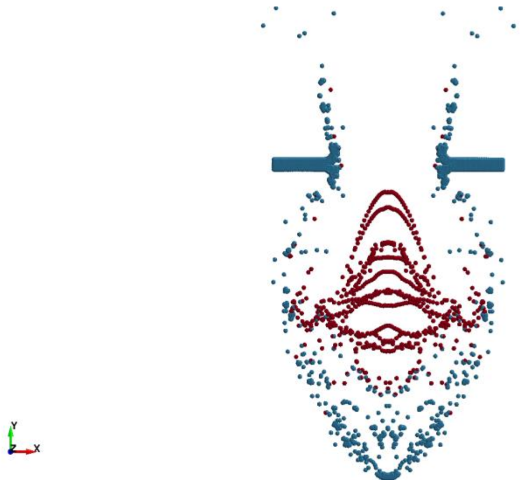
Contact

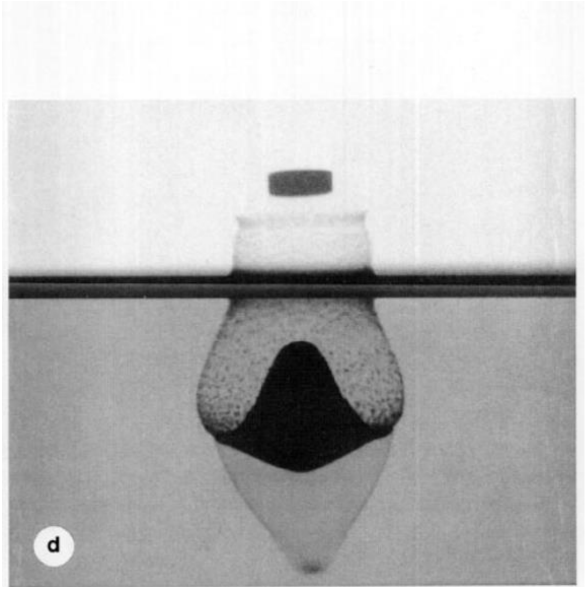
Subcycling

Coupled to LLNL-Dyna3D FEM solver

Starting Point

Hypervelocity Impact (1997)





Experiment Image from Libersky et al (1993) J Comp Phys 109, 67-75

Fluid-structure interaction

Fluid-structure interaction

Interested in structural response

Sloshing ESA

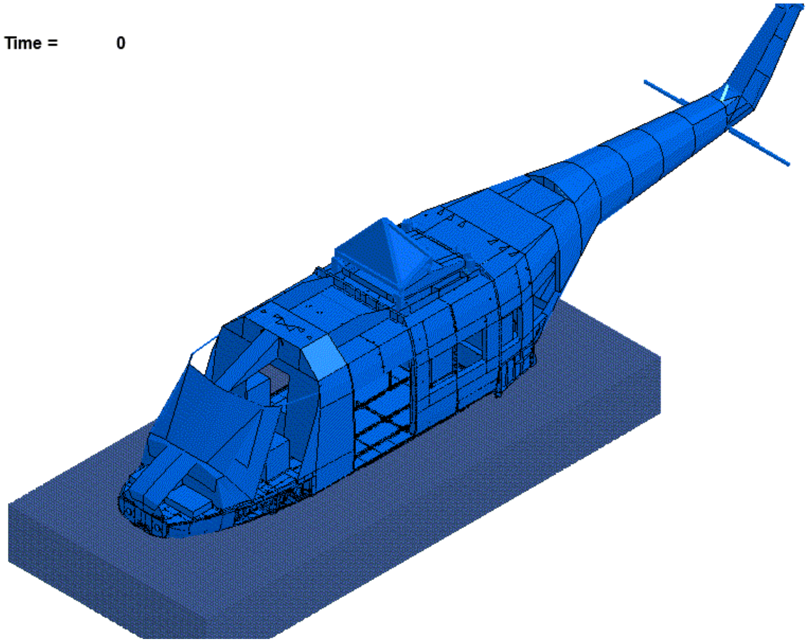
Explosive forming

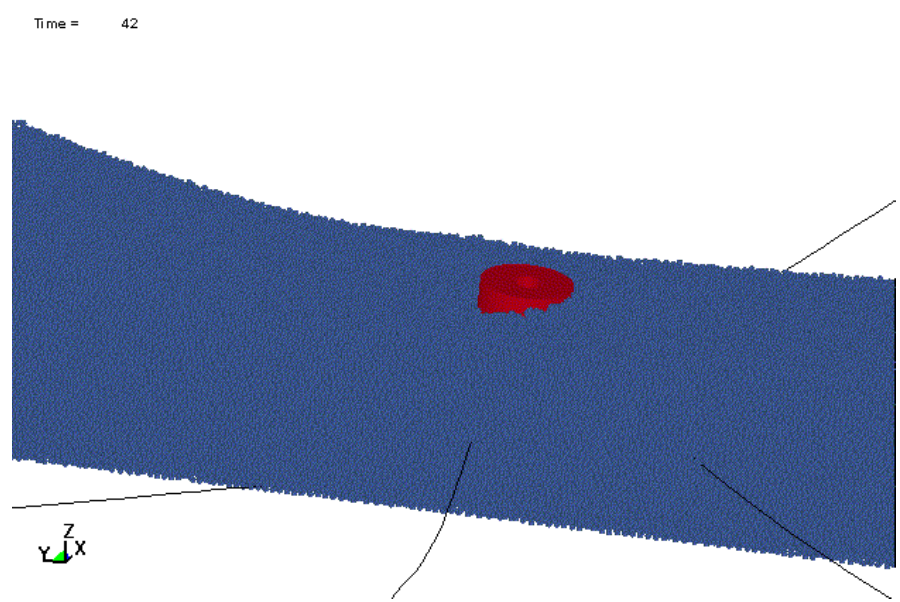
Ditching helicopter/aircraft

Extreme wave Buoy/wave impact

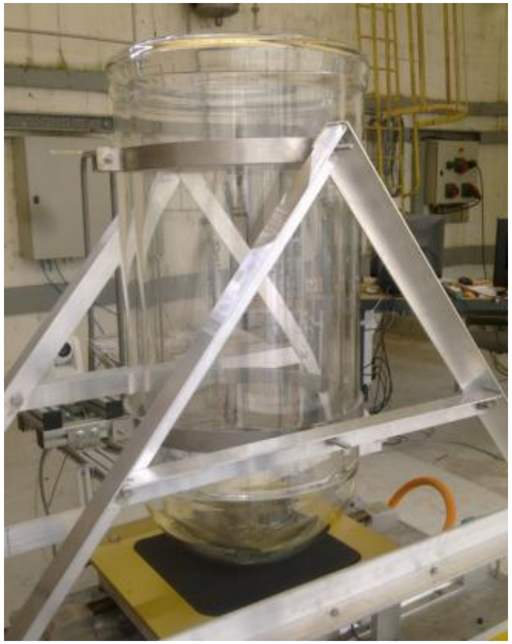
Analysis of Extreme Loading

Applications:





Sloshing



A cylindrical tank (with a hemi-spherical base):

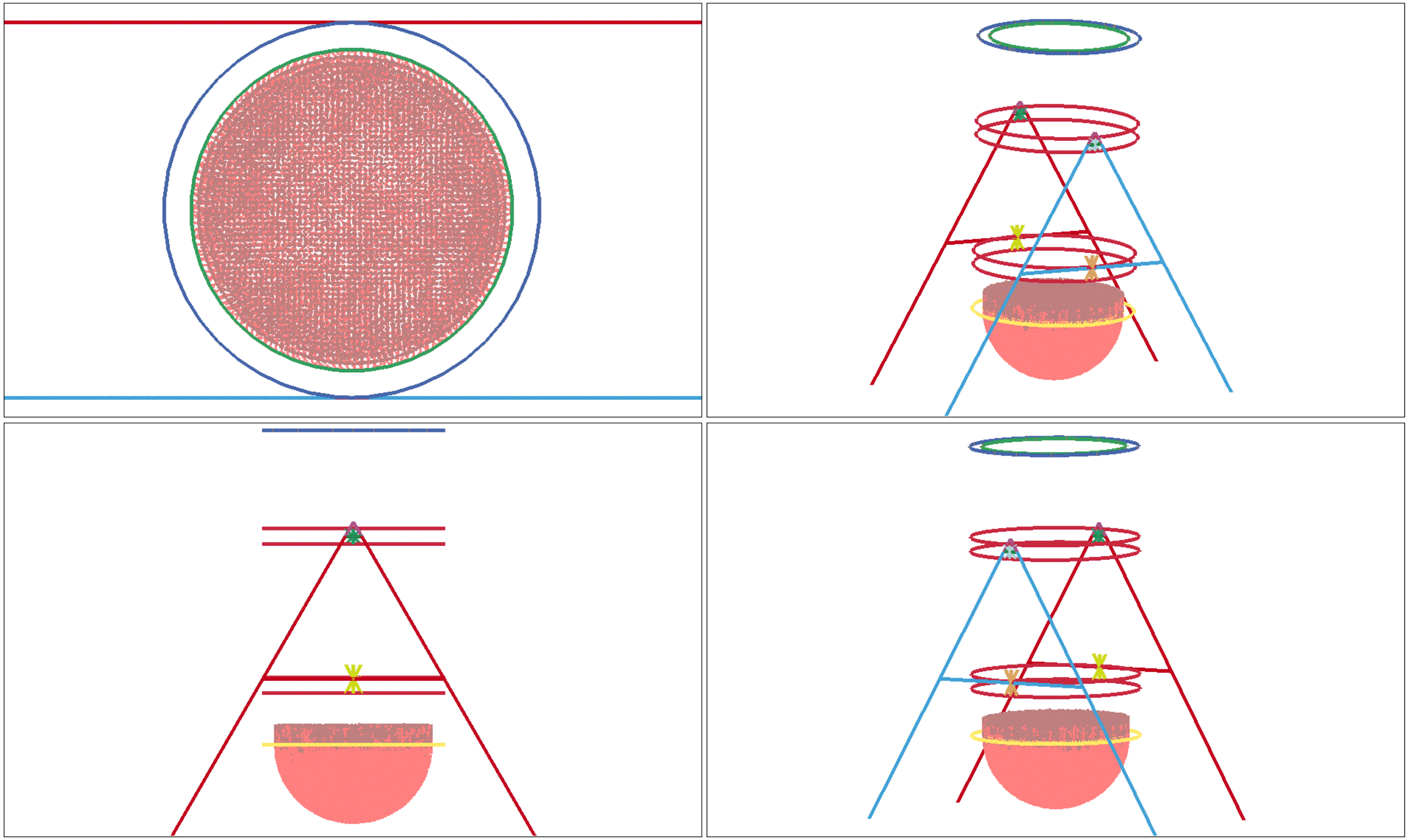
- Partially filled
- Subjected to Constant frequency base excitation.

The measured parameters are:

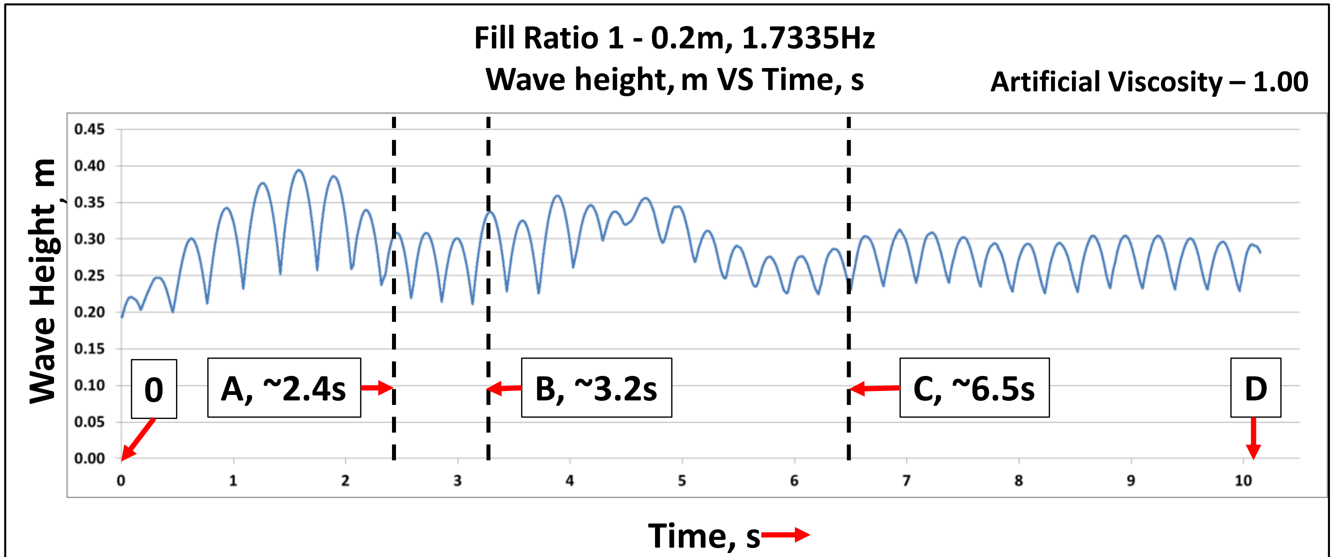
- Sloshing force (the reaction force at the attachment of the tank support structure to the shaker table),
- Interface force between the tank and the support structure,
- Fluid motion

Sloshing

Constant sweep frequency

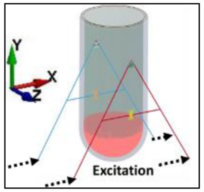


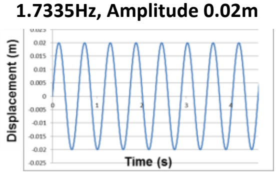
Sloshing



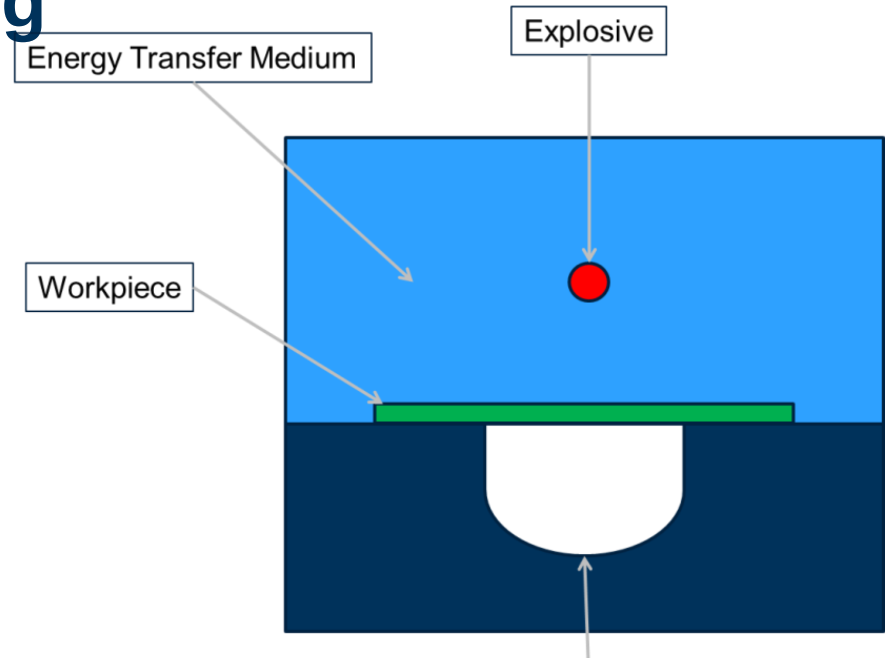
Maximum Wave height ~ 0.4006m at time 1.58231s

Region	Water motion
0A	Sloshing
AB	Transition from Sloshing to Swirling
BC	Initial Swirling
CD	Steady/stabilised Swirling

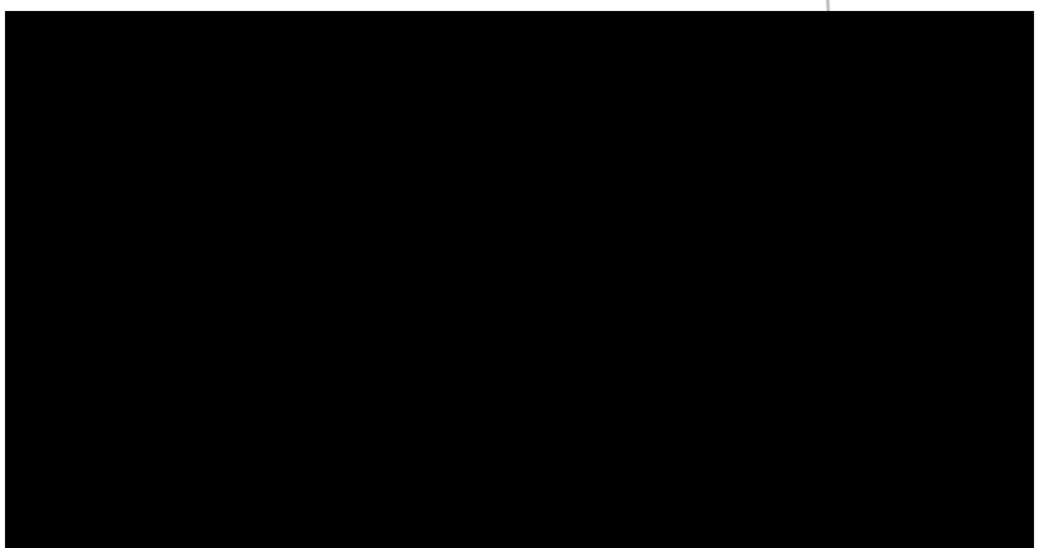




Explosive forming

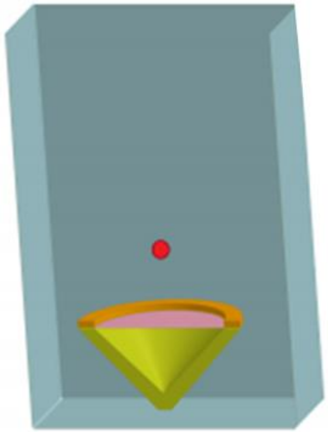


- Explosive forming
- Main components involved:
  - Explosive Charge
  - Energy Transfer Medium
  - Forming Die + Clamping
  - Workpiece

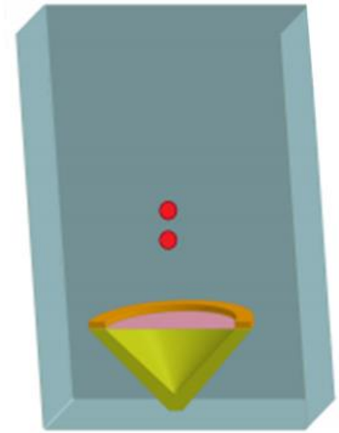


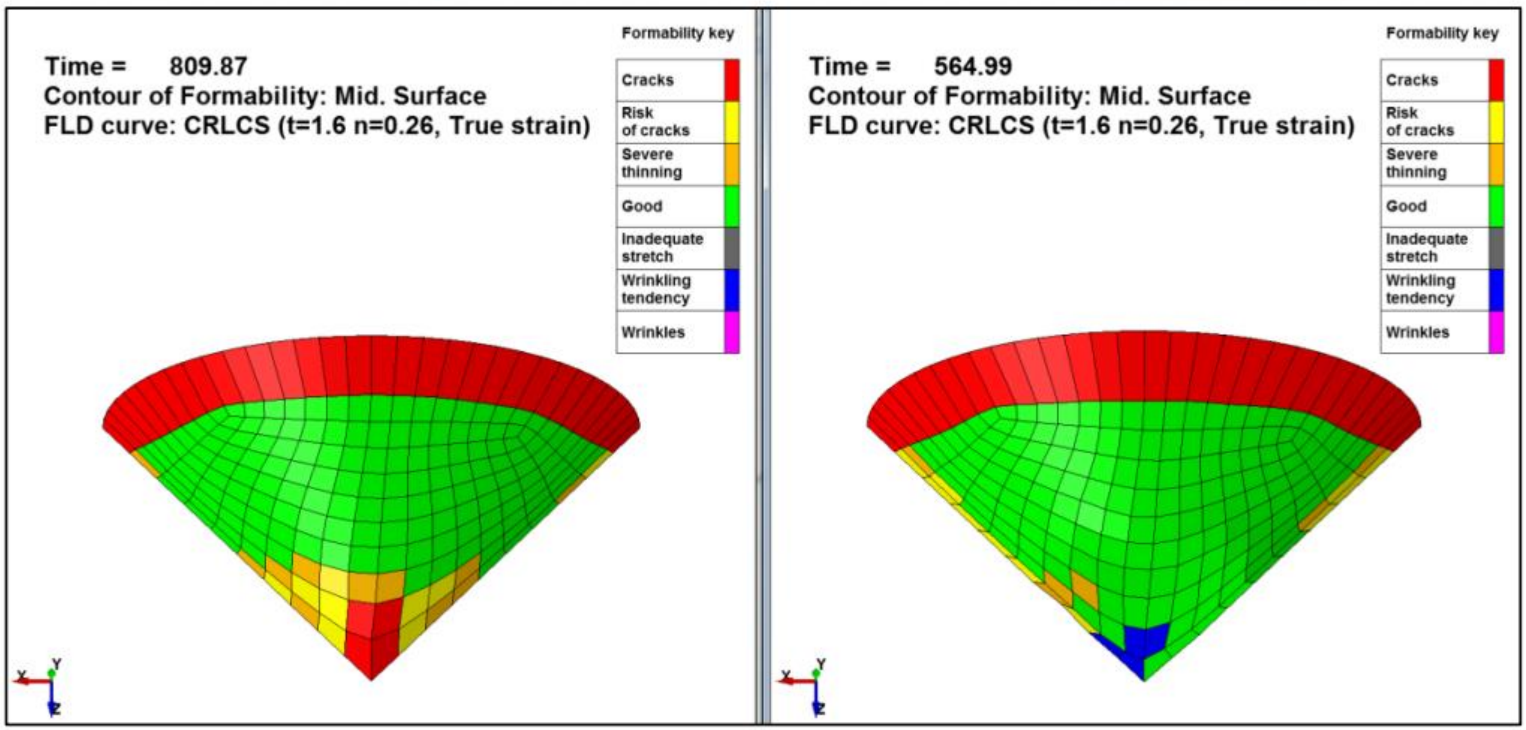
Explosive forming

single explosive

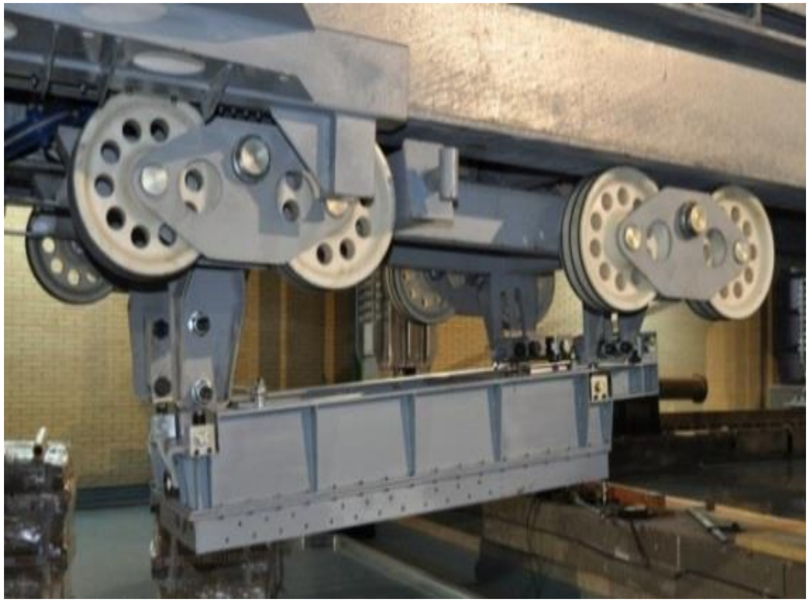


multi explosive 3



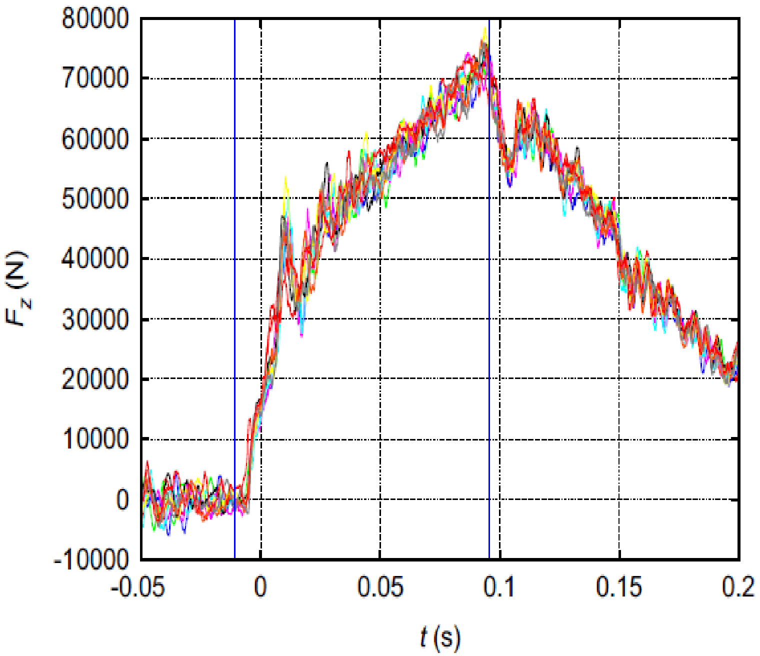


Low angle water impact



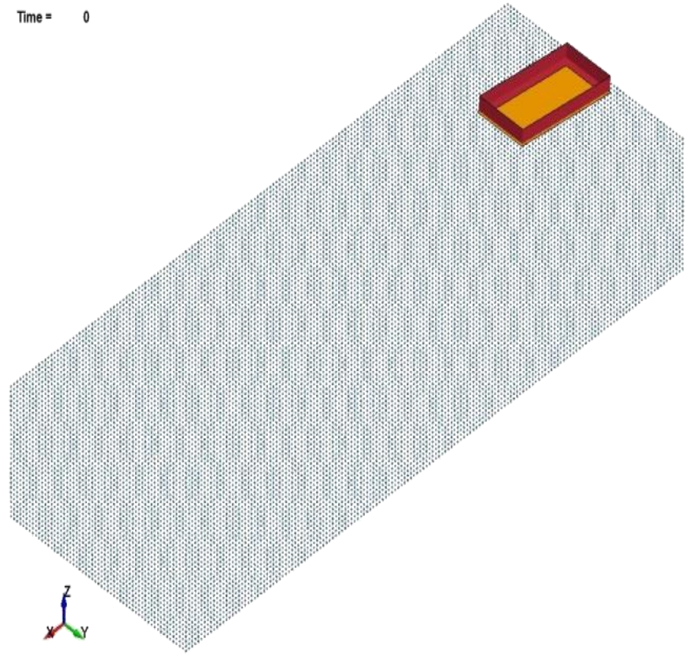
Part of FP7 SMAES project, using guided water impact facility (INSEAN) developed to allow high-velocity, low angle water impact experiments.

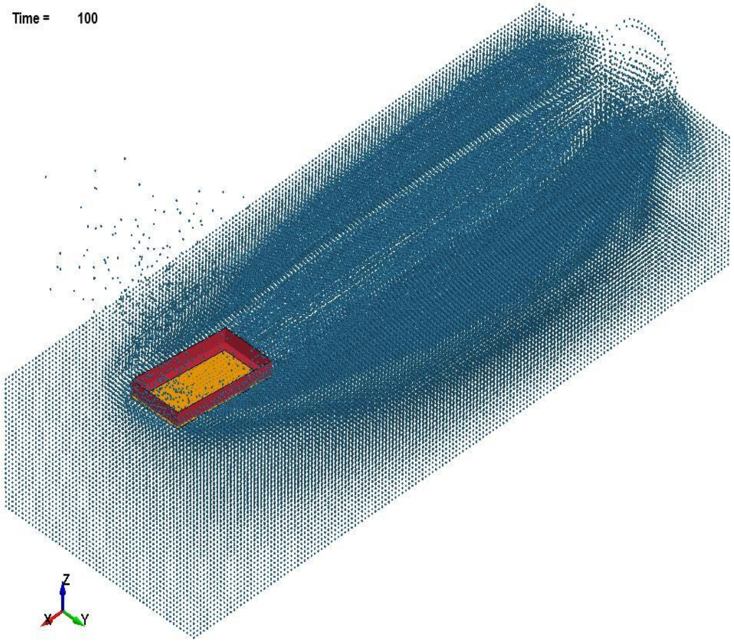
- 47 tests on flat & curved thick plates
- 17 tests on metallic and composite deformable plates
- 2 tests on stiffened panel component



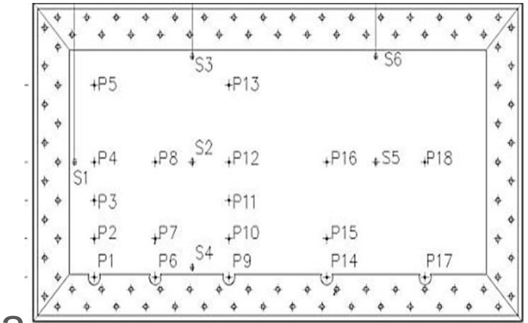
Low angle water impact

Structural component
(underwater view)





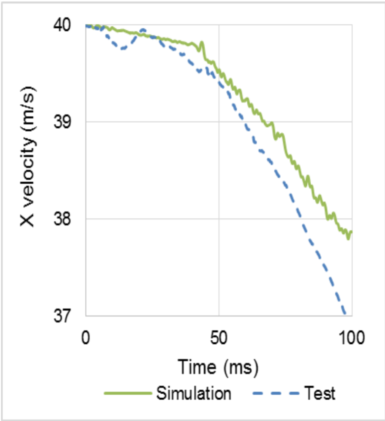
Low angle water impact

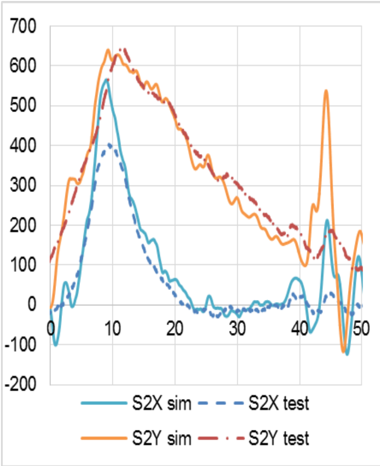


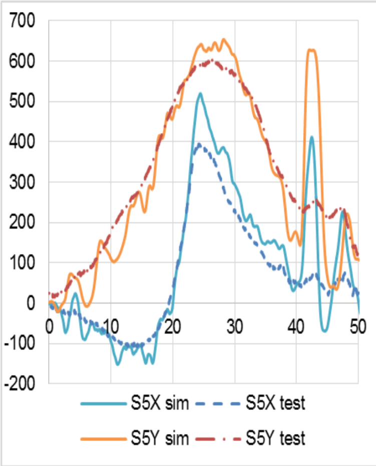
Velocity

Strain gauges

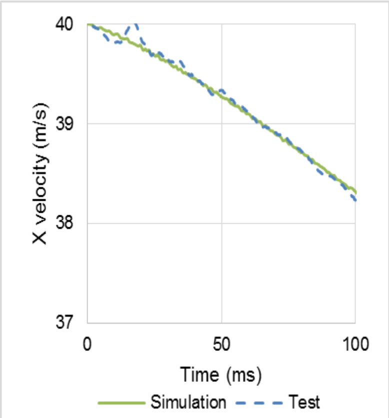
4º pitch

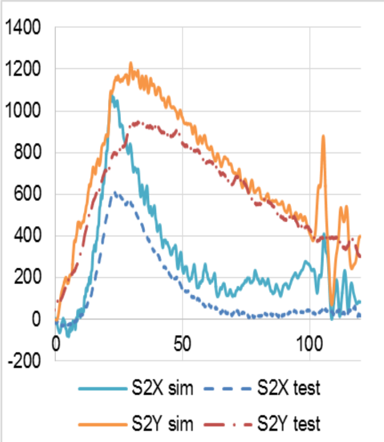


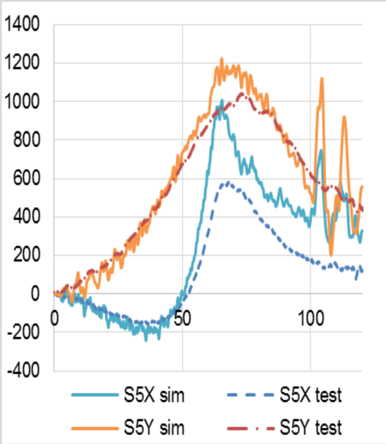




10º pitch

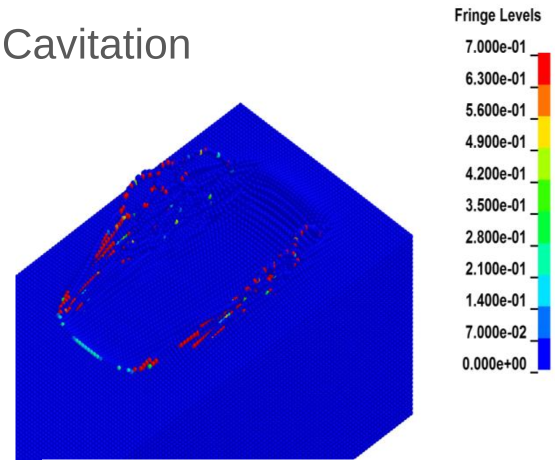


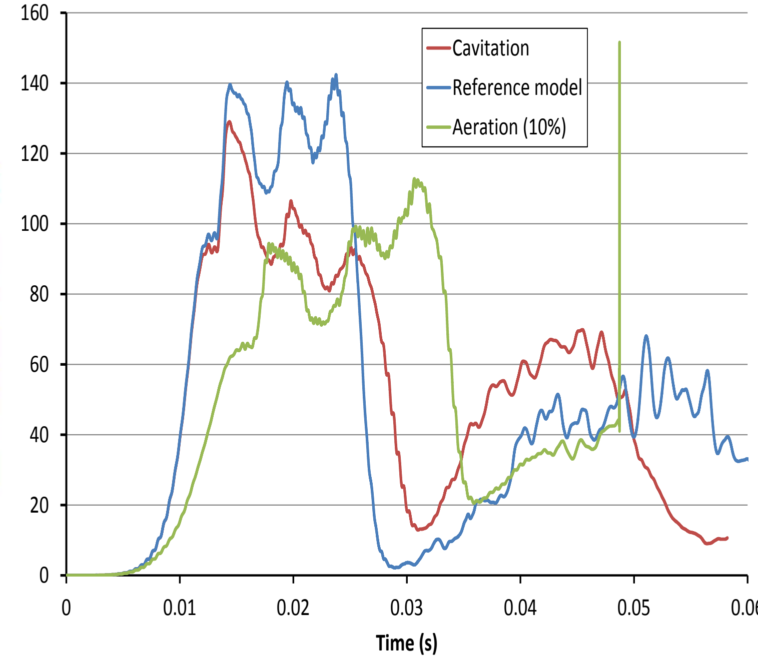


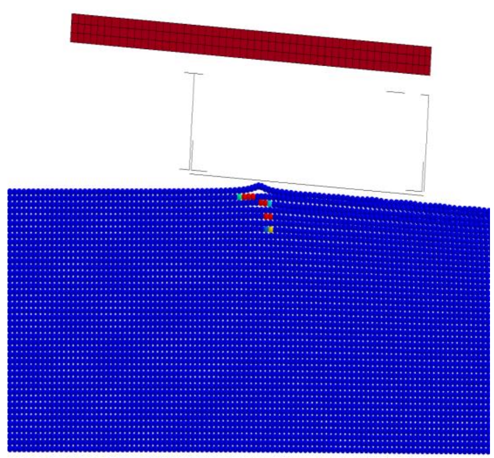


Low angle water impact

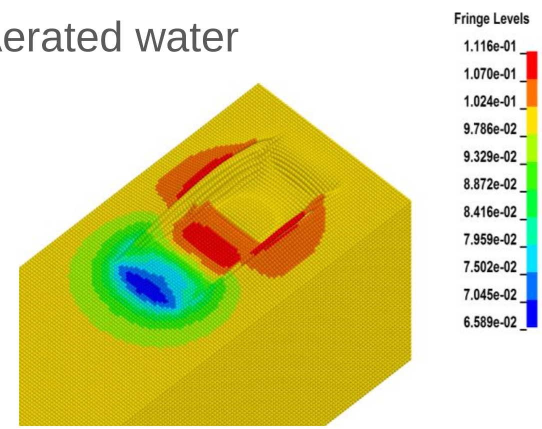
Cavitation







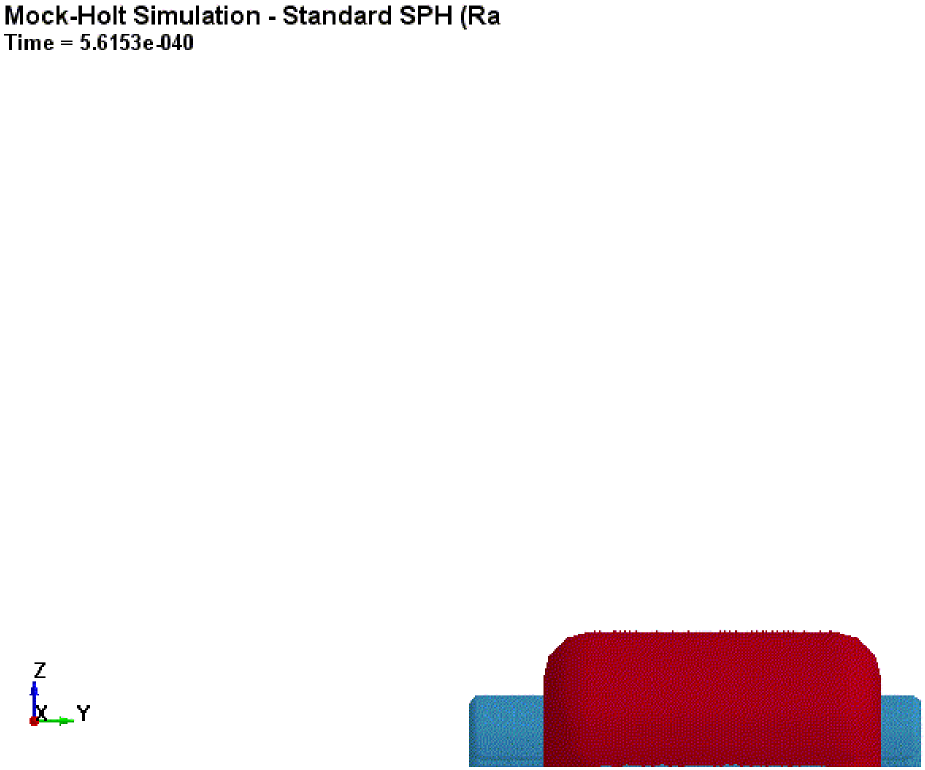
Aerated water

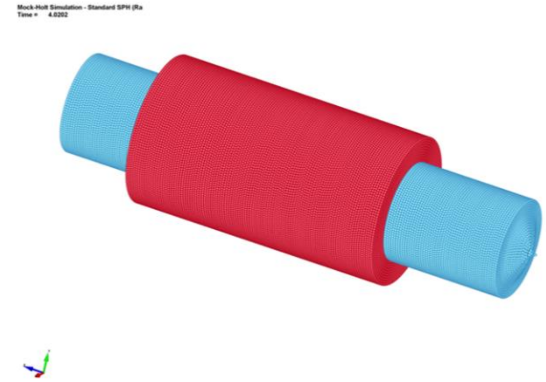


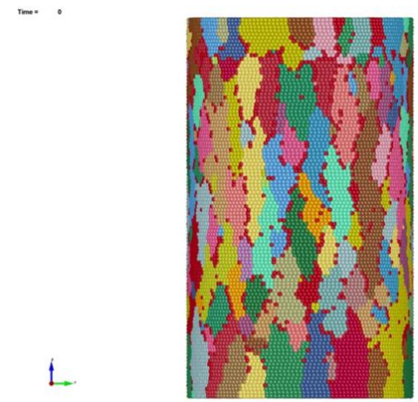
Solid mechanics examples

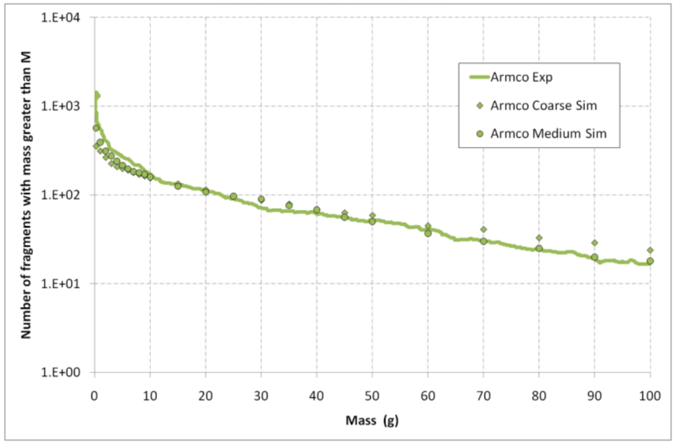
Fragmentation

Explosively driven

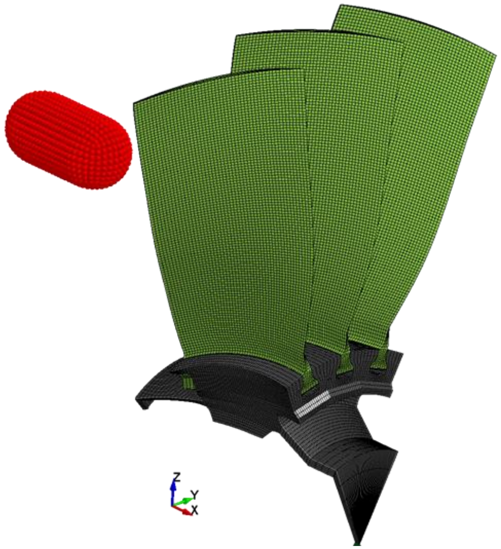


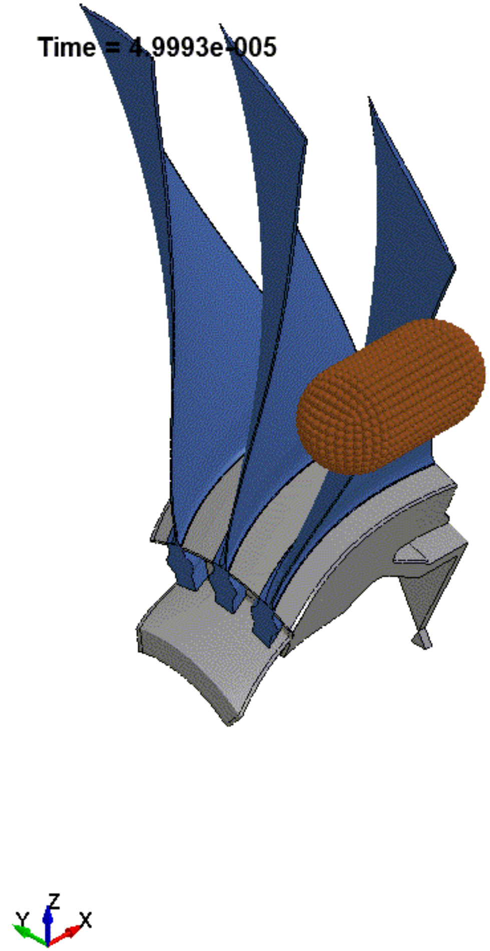


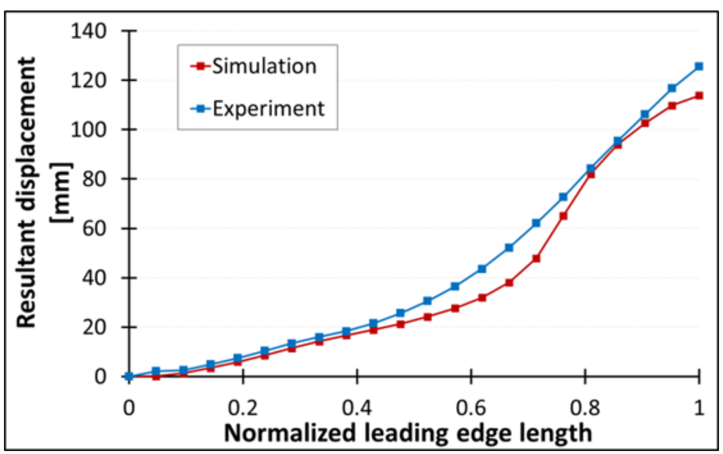




Bird Strike

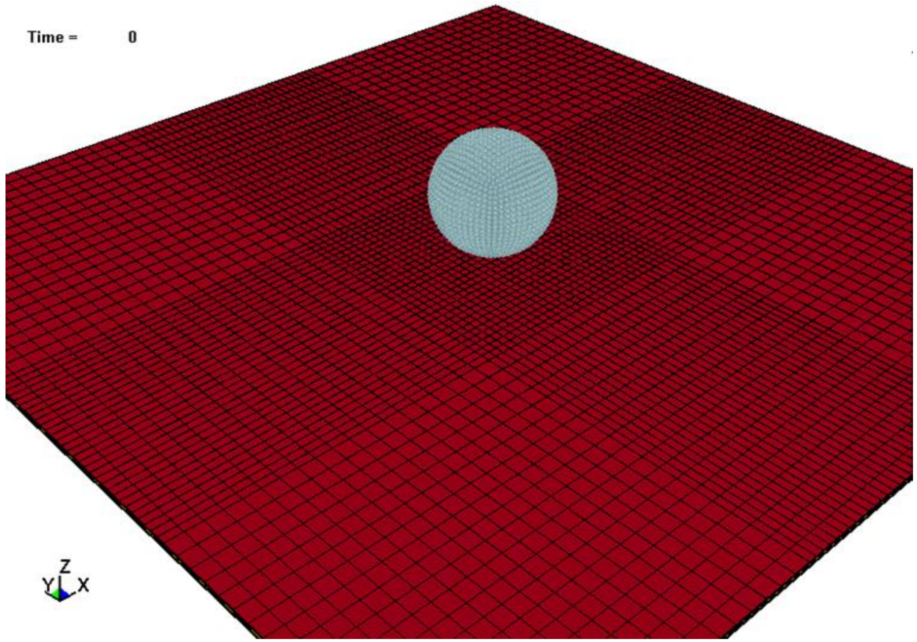




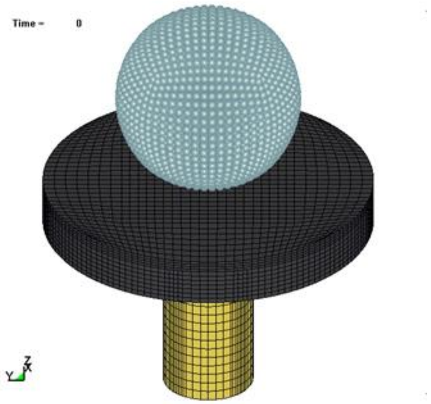


Vignjevic et al. (2013) International Journal of Impact Engineering, 60, 44-57

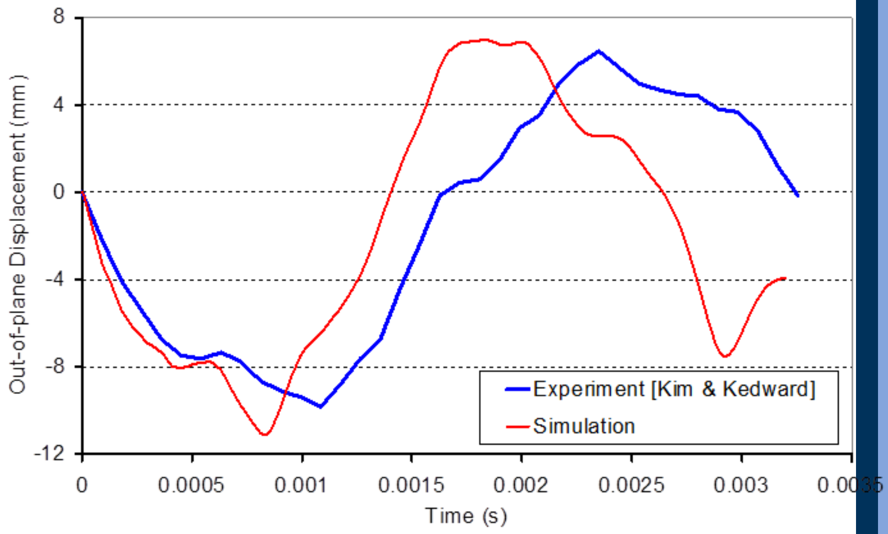
Ice Impact



Time = 0
Z
Y
X

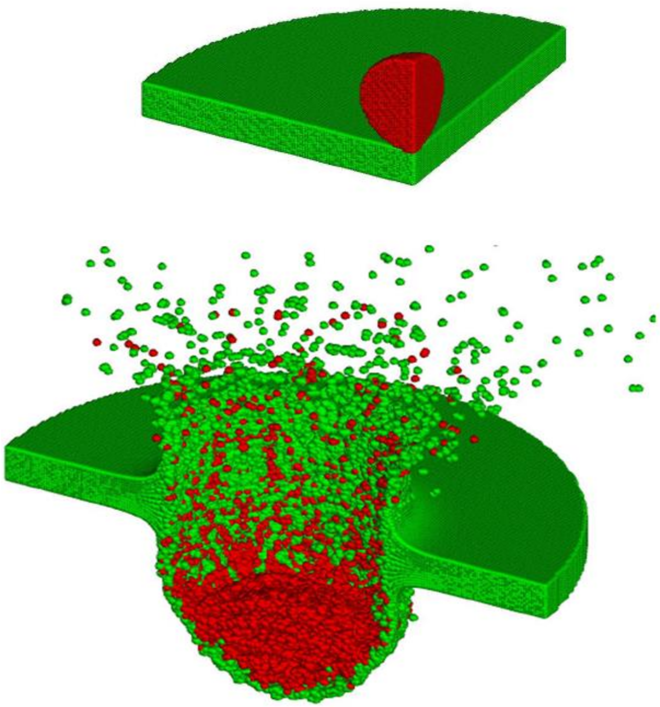


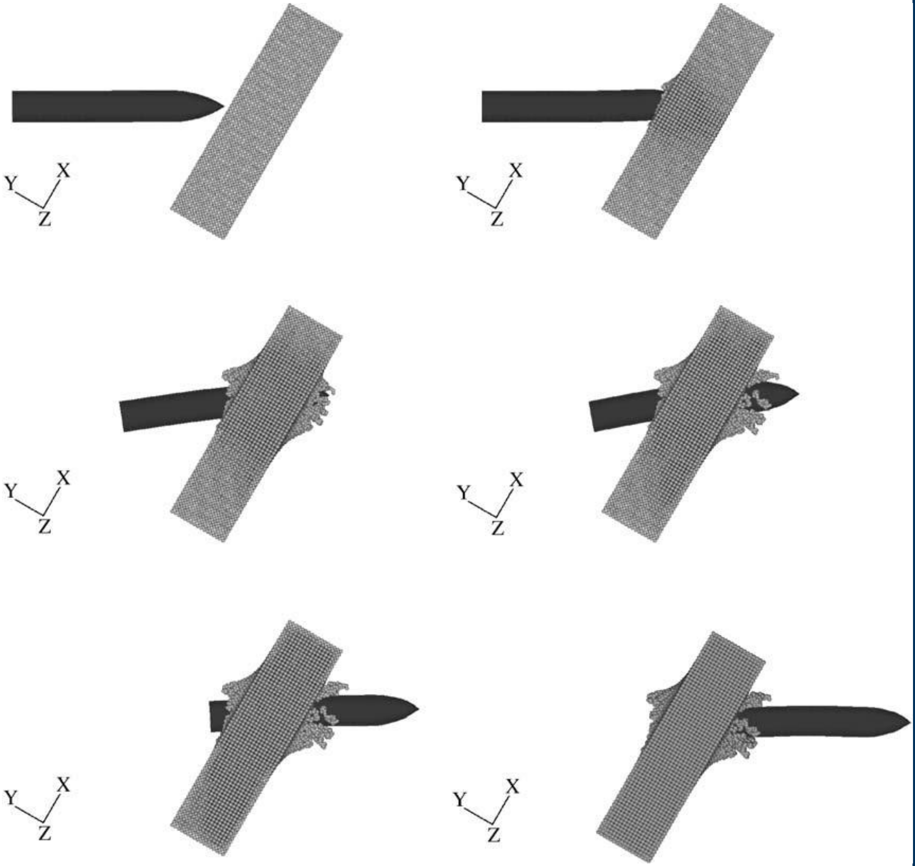
Time = 0



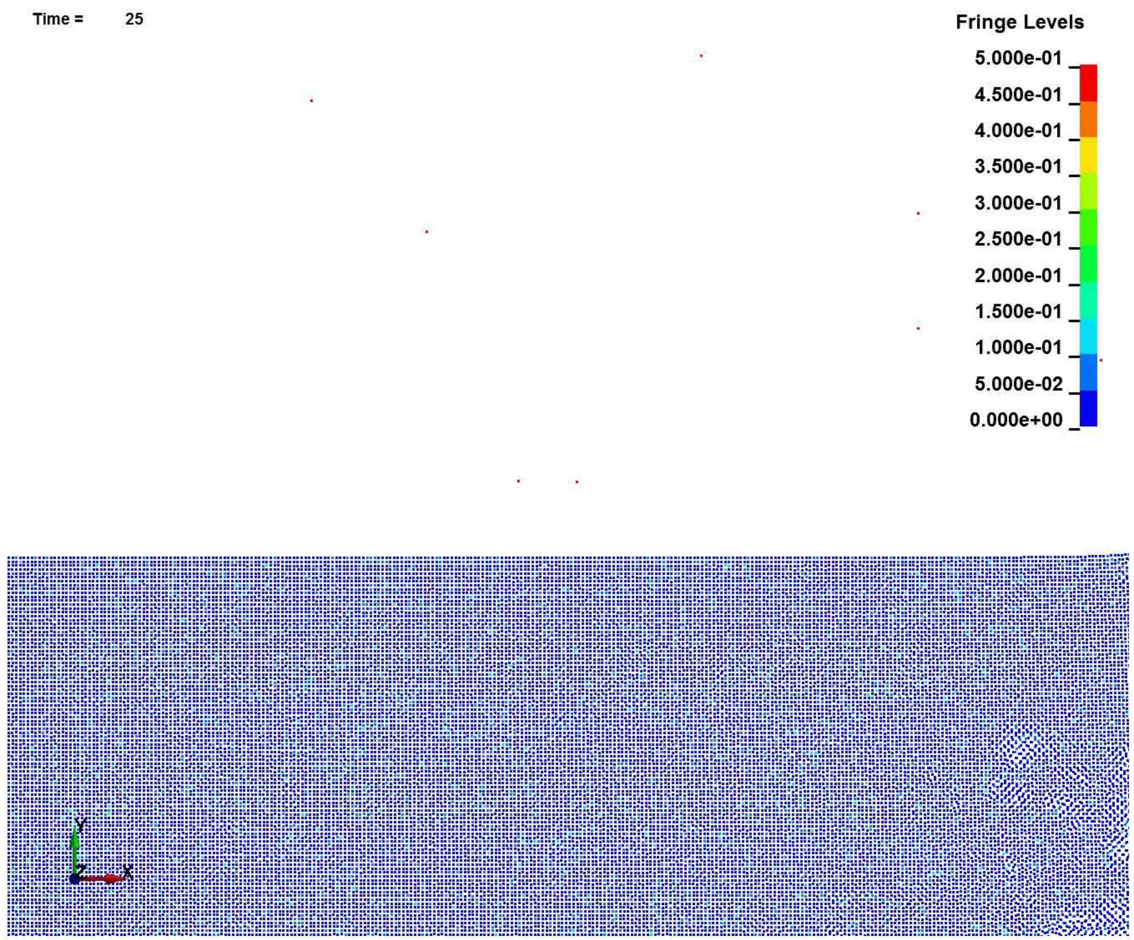
8
4
0
-4
-8
-12
Out-of-plane Displacement (mm)
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
Time (s)
Experiment [Kim & Kedward]
Simulation

Ballistic/Hypervelocity Impact





Machining



Time = 25
Fringe Levels
5.000e-01
4.500e-01
4.000e-01
3.500e-01
3.000e-01
2.500e-01
2.000e-01
1.500e-01
1.000e-01
5.000e-02
0.000e+00
Y
Z
X

Solid mechanics current work

The work presented forms part of H2020 project EXTREME (grant agreement No 636549) on dynamic loading of composite structures

www.extreme-h2020.eu

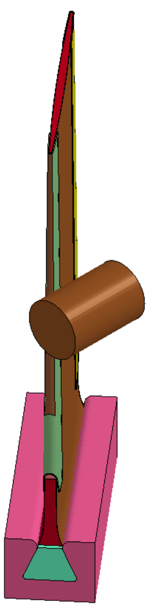
Solid mechanics current work

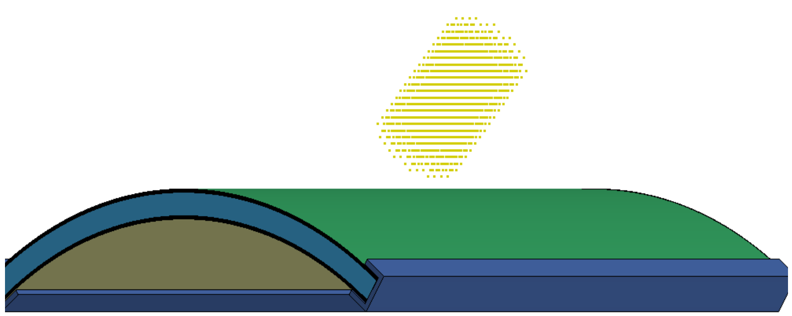
Dynamic loading of composite materials

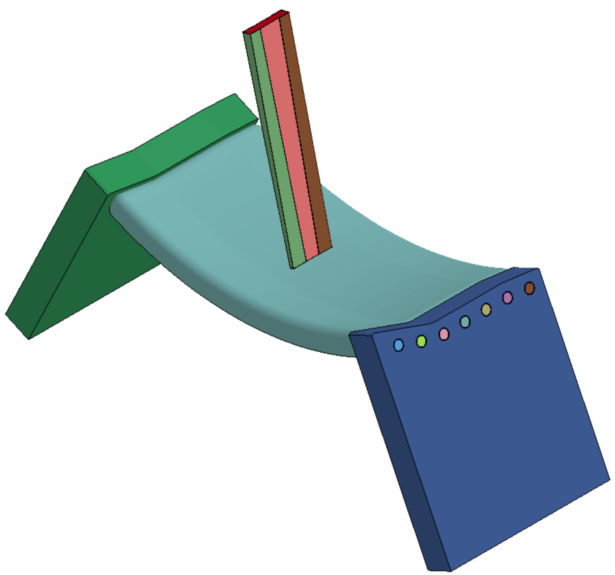
- Strain softening
- Interaction area damage
- FE-SPH coupling and adaptivity

Applications

- Birdstrike and debris impact on flat panel
- Birdstrike fan, engine cowl, leading edge
- Debris impact on stiffened panel
- Blade-off

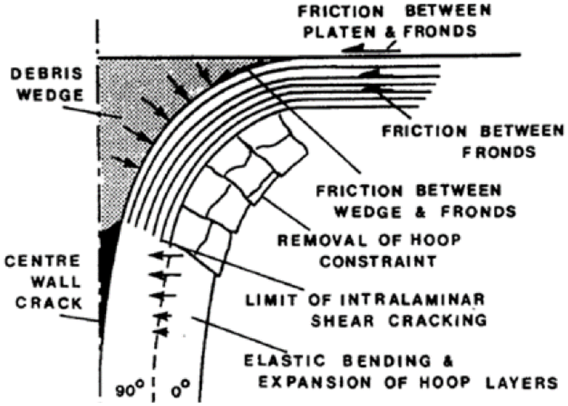


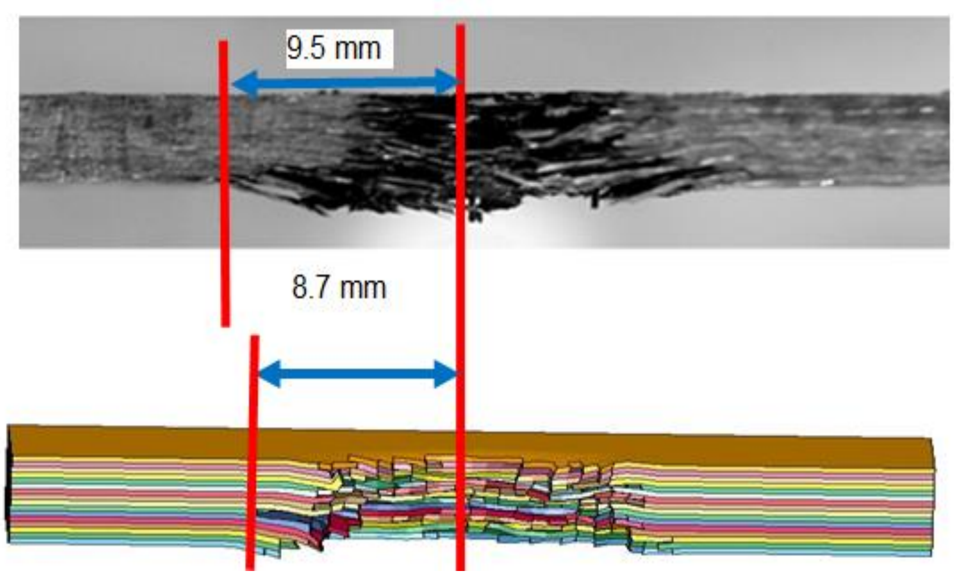




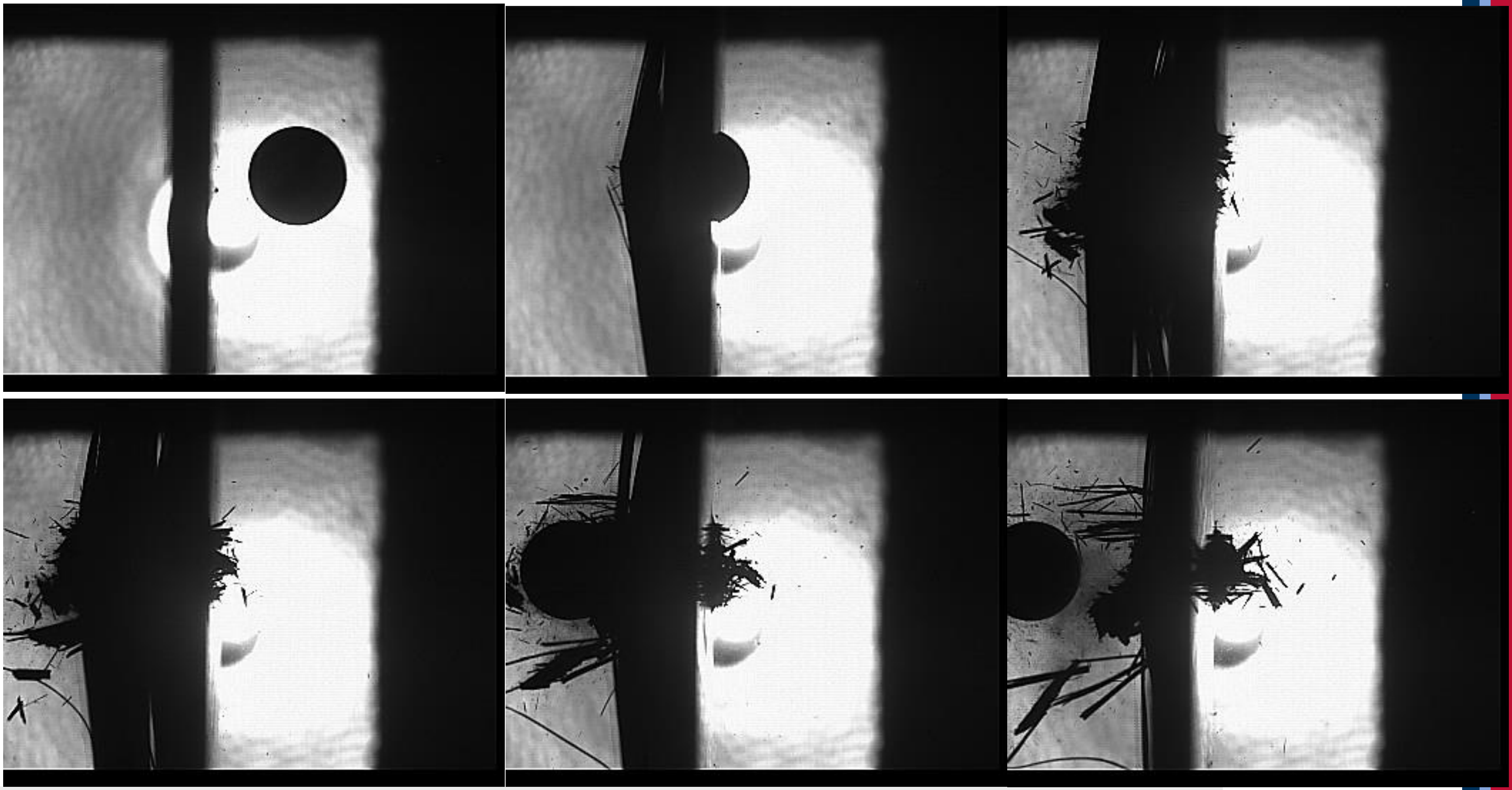
Solid mechanics current work

- During FEM simulations of impact on CFRP excessive element deletion can be a problem





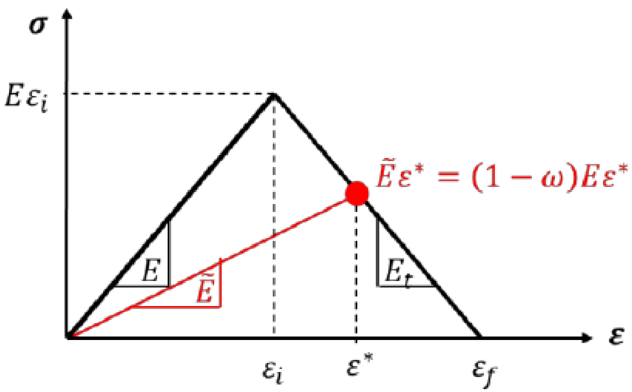
Solid mechanics current work

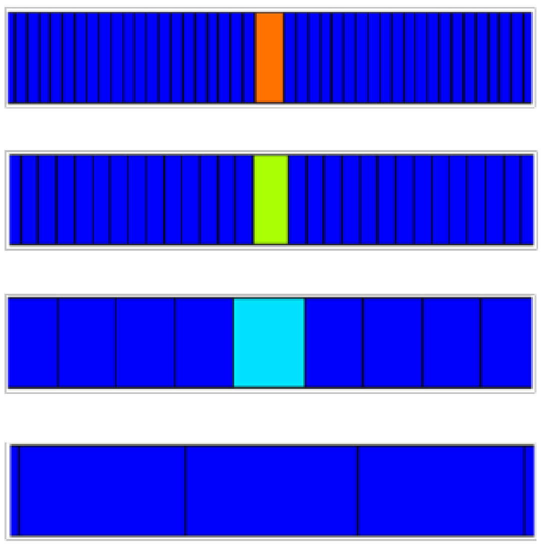


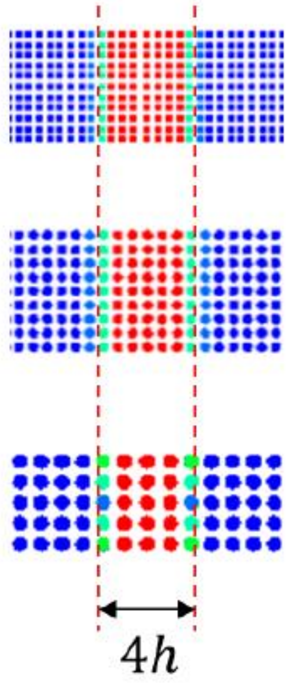
Non-local properties – strain softening

SPH as Non-local Regularisation Method

FEM SPH







Vignjevic et. al. (2014) Comput. Methods Appl. Mech. Engrg. 277, 281–304

Interaction Area Damage

$$F = \sigma \cdot A$$

Swegle Interaction Area*

Force on particle ***i***

$$\langle m_i \ddot{u}_i \rangle = \langle F_i \rangle = -\sum_{j=1}^{np} m_i m_j \left(\frac{P_i}{{\rho_i}^2} + \frac{P_j}{{\rho_j}^2} \right) \nabla_i W_{ij}$$

can be rewritten as:

$$F_i = -\sum_j \left[P_i \frac{\rho_j}{\rho_i} + P_j \frac{\rho_i}{\rho_j} \right] A_{ij}$$

with: $A_{ij} = V_i V_j \nabla_i W_{ij}$

* J.W. Swegle, *Conservation of momentum and tensile instability in particle methods.*, USA: Sandia National Laboratories, 2000. SAND2000-1223

Interaction Area Damage

Standard approach (Kachanov, Lemaitre) in damage mechanics:

- A damage variable, D represents an effective surface density $\tilde{A}$ due to presence of microscopic cracks or voids within the material

$$\tilde{A} = A\,(1 - D)$$

- Leads to concept of an effective stress

$$\tilde{\sigma} = \frac{\sigma}{(1 - D)}$$

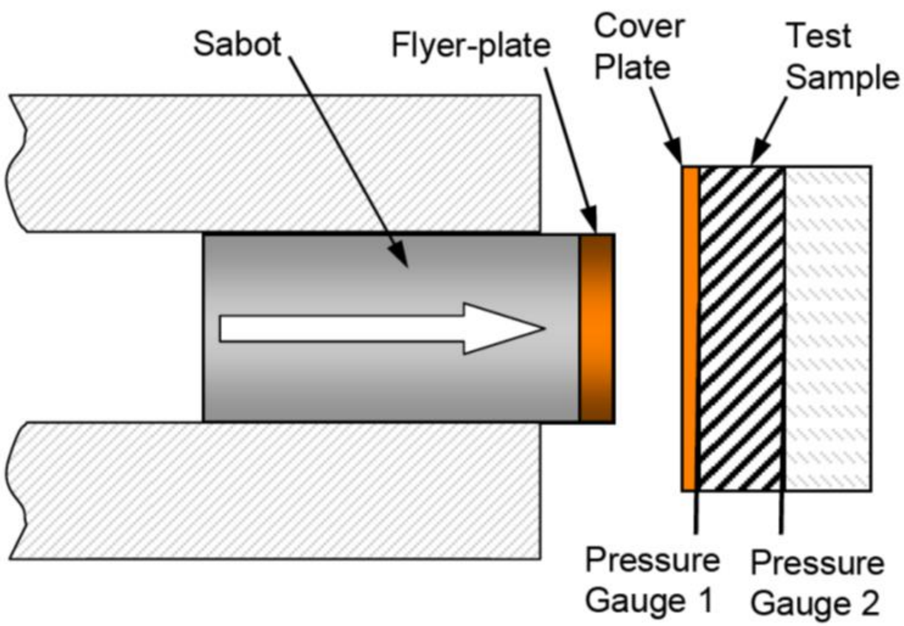
* *Kachanov LM. Time of the rupture process under creep conditions*. Izv. Akad. Nauk., S.S.R., Otd Tech Nauk 1958;8(8):26-31

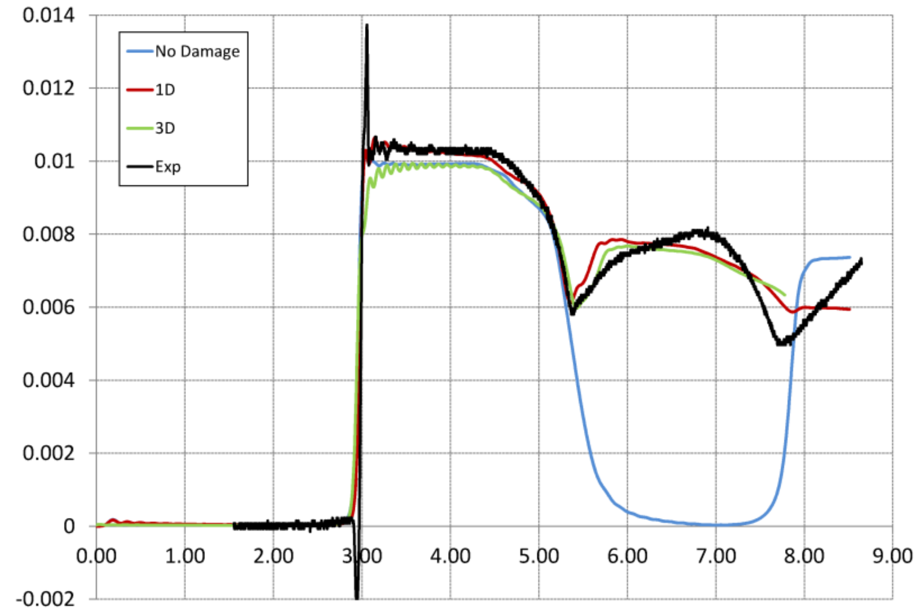
Interaction Area Damage

- Impact on brittle material modelled with isotropic elastic with failure stress;

Interaction Area Damage

17 July 2019





Coupling Algorithms

- Belytschko
- Huerta and Fernandez-Mendez

Domain discretised with a set of particles and a set of FE, where particles are not exactly located at the FE nodes ;

Blended shape function methods with higher order reproducibility;

Particle shape functions are modified to improve the quality of the approximation taking into account the interpolation functions and positions of active FE nodes and the particles;

FE shape functions for the non active elements are switched off;

Interpolation space within element replaced by contributions from neighbouring particles and red nodes only;