Metafor

Large strains thermo-mechanical Finite Element software

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Scope

1. Introduction
2. Metafor
3. Interesting features
4. ALE formalism
5. Numerical examples
6. Future

Introduction

Introduction

LTAS-MN²L (ULg) – Prof J.-P. Ponthot

- ***ULg*** = University of Liège (8 faculties – 400 professors – 2000 researchers – 17000 students / 20% foreigners)
- ***LTAS*** = Laboratoire des Techniques Aéronautiques & Spatiales (Aerospace Laboratory) – includes 8 laboratories ~ 60 engineers
- ***MN²L*** = Mécanique Numérique Non Linéaire (Non-Linear Mechanics)

Introduction

General research interests

- Process simulation including large strains (Prof Ponthot)
  - Material forming
  - Crash & impact problems
  - Tire Mechanics
  - Biomechanics

Main Industrial partners

- GDTech / Samtech (Engineering services)
- ArcelorMittal (Steel maker)
- SNECMA (Aero engines manufacturer)
- TECHSPACE-AERO (Aero engines manufacturer)
- SABCA (Ariane 5 components)
- SONACA (Airbus components)
- GOOD-YEAR (Tire manufacturer)

Metafor

Our home-made software : Metafor

What is it?

Nonlinear finite element software mainly used for the simulation of Metal Forming processes.

History

- 1992 Metafor – Fortran77 (Ponthot's thesis).
- 1992-1998 Awkward integration of some PhD theses.
- 1998 Unmanageable situation – new routines added using C.
- 2000 Oofelie was discovered – complete rewriting using C++/python.
- 2000-2008 All developments integrated inside one software : Metafor.

Current Metafor team

R. Boman , G. Deliége, PP. Jeunechamps, O. Karaseva, R. Koeune, M. Mengoni, L. Noels, L. Papeleux, L. Vigneron.

Our home-made software : Metafor

Our aims

- Never loose the previous developments (PhDs, research projects,…).
- To gather the researchers together on a unique software platform.
- Full control of the source code.

"Basic" FEM Toolkit

Our tools

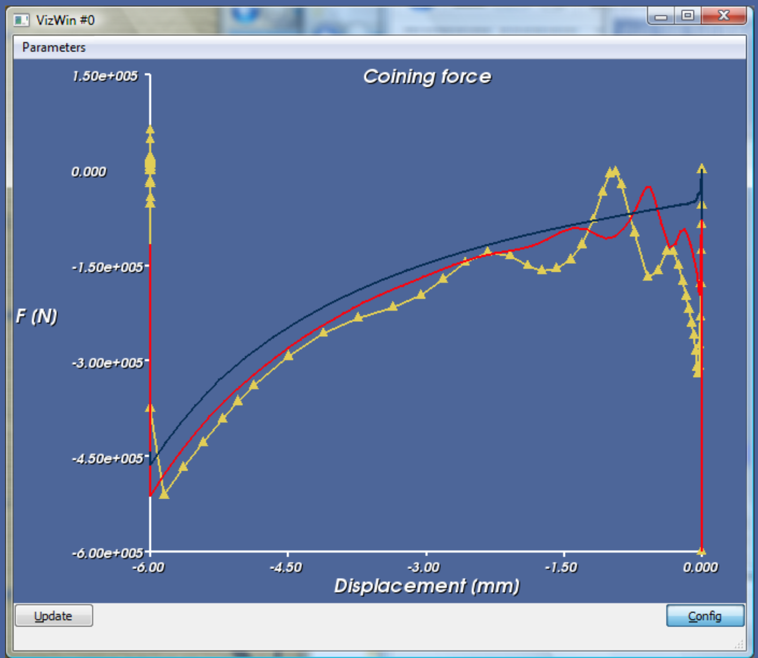
- C++/python : common language
- SVN : 1-2 releases / week
- Tests suite : >1200 tests on 01-09-2010
- Doxygen : programmer's documentation
- Web site : user's documentation (in French)
- Programming rules : (simplified) "Ellemtel" coding rules

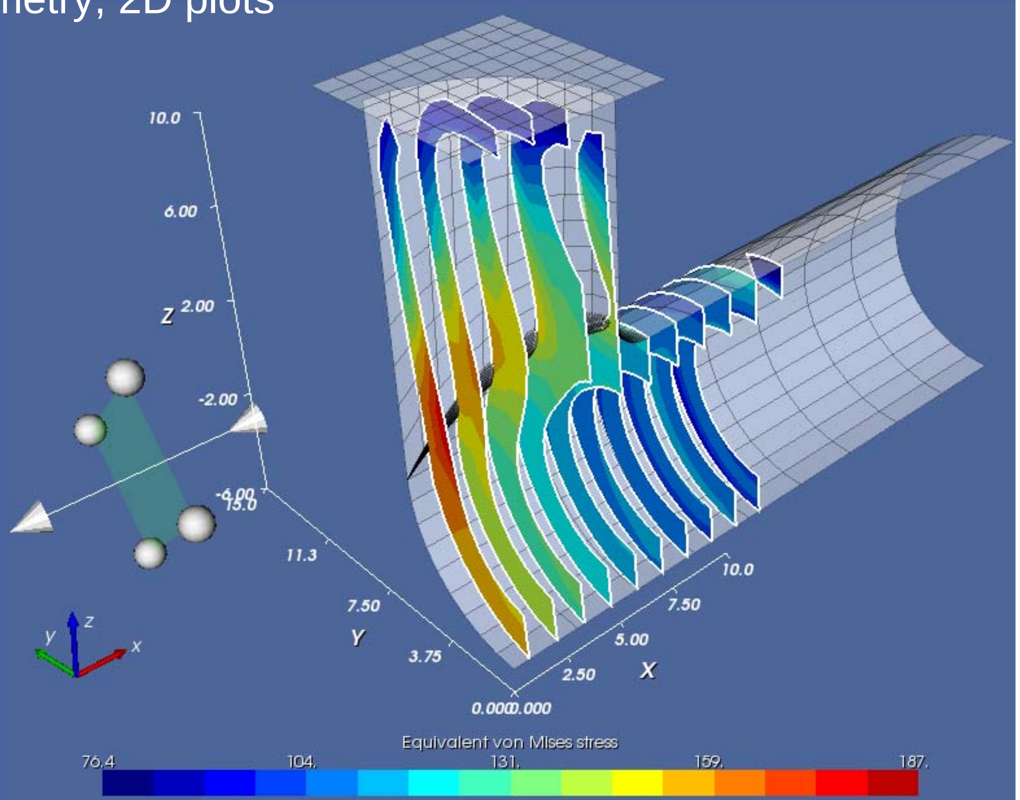
Interesting features

1. Real time visualization
2. Meshers
3. Large strain elements
4. Optimizations
5. Python interpreter

Real-time visualization

- Multithreaded : Separated from the worker (computational) thread
- Limited preprocessing features
- Extended post-processing features
- Interactive cutting, texture mapping, symmetry, 2D plots
- Automatic generation of movies





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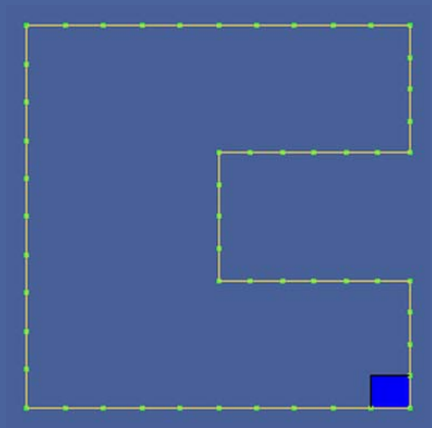
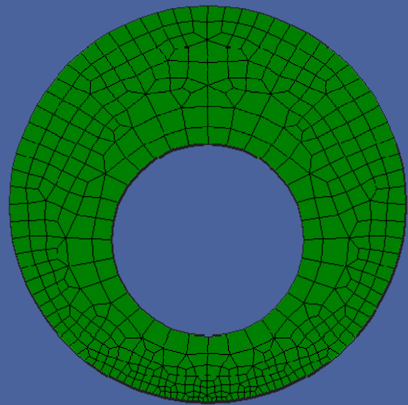
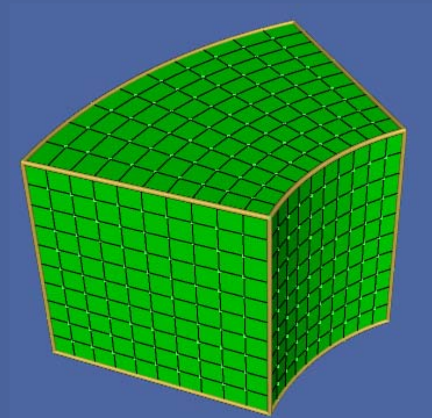
1D - 2D - 3D Meshers



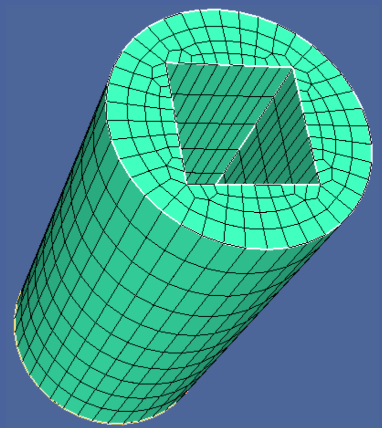
Frontal/Offset mesher in 2D



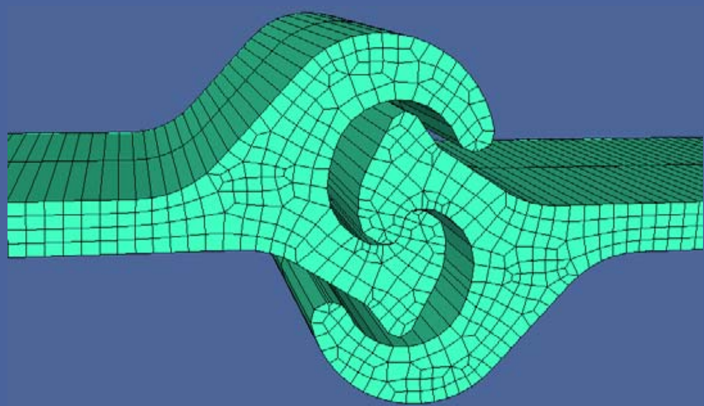
Unstructured Quad based on a background mesh (Gen4)



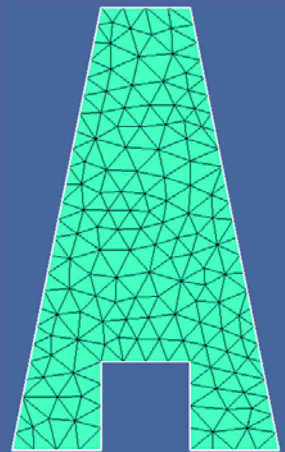
Transfinite meshers in 2D / 3D



Basic 3D linear extrusion

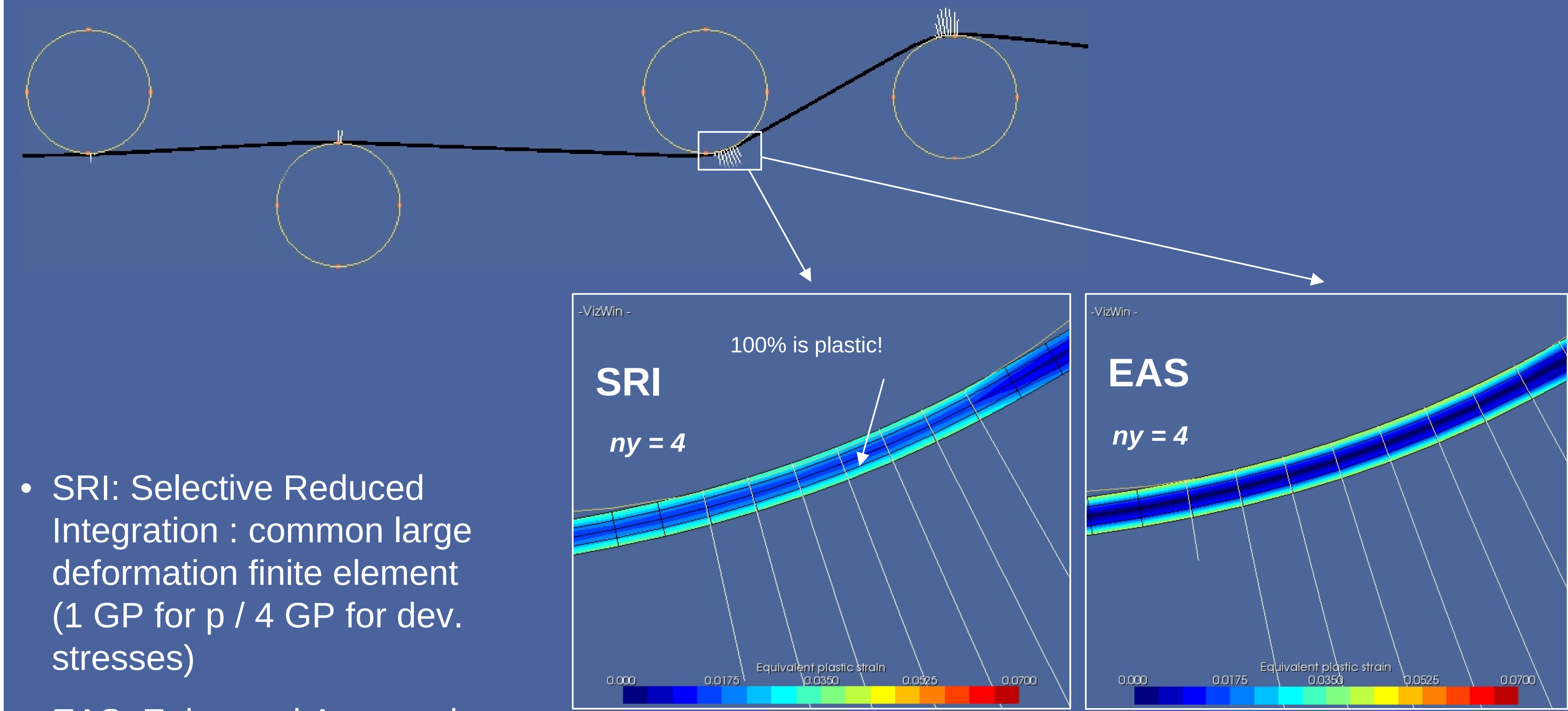


Importing from Samcef, Patran, Gmsh, …



Delaunay 2D / 3D

Large strains elements – SRI & EAS elements

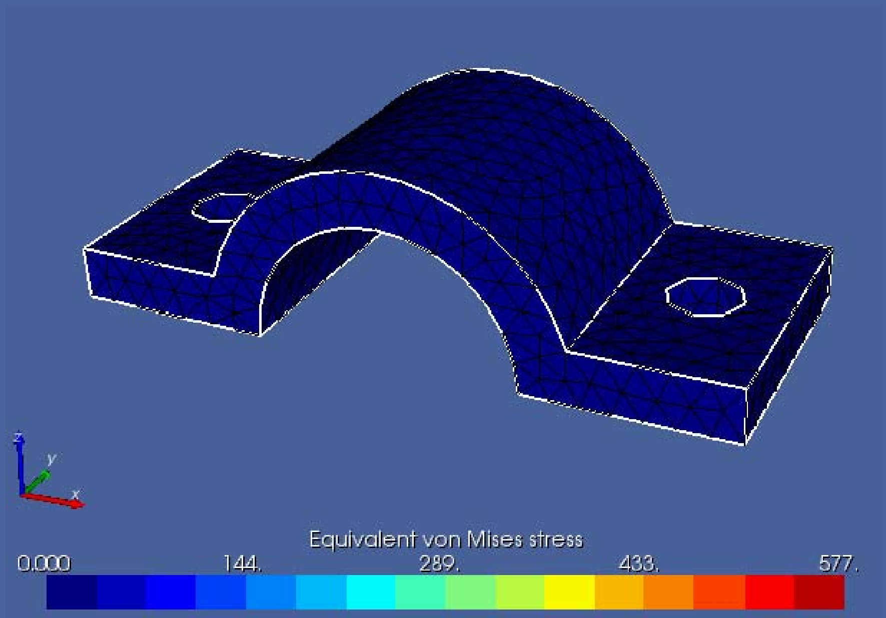


- SRI: Selective Reduced Integration : common large deformation finite element (1 GP for p / 4 GP for dev. stresses)
- EAS: Enhanced Assumed Strain : avoids SRI shear / volumetric locking

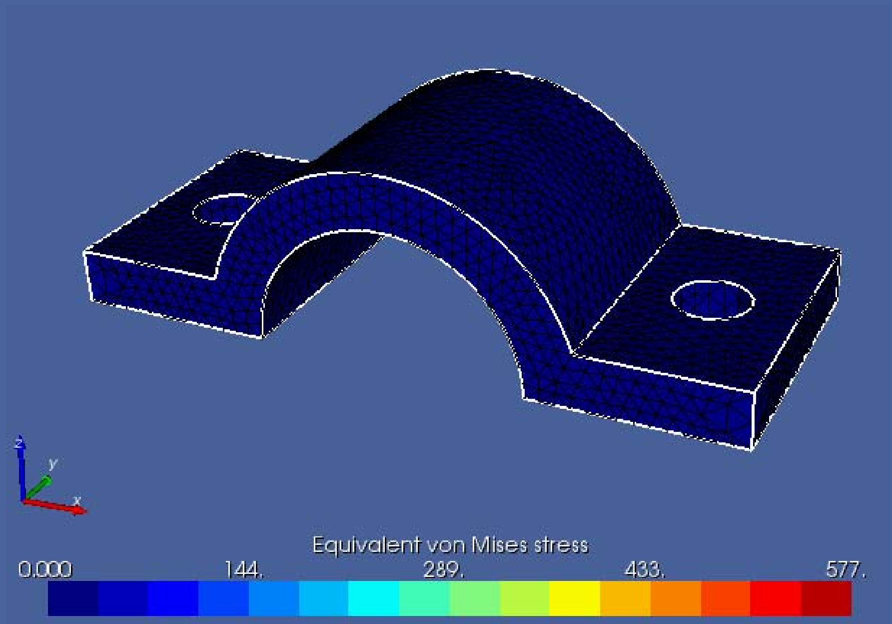
Quadratic non-linear finite elements

- 2D: 6-noded triangles, 8-noded quads
- 3D: 10-noded tetrahedrons

Linear tetrahedrons



Quadratic tetrahedrons



Quad-tetras are divided into linear-tetras for vizualisation

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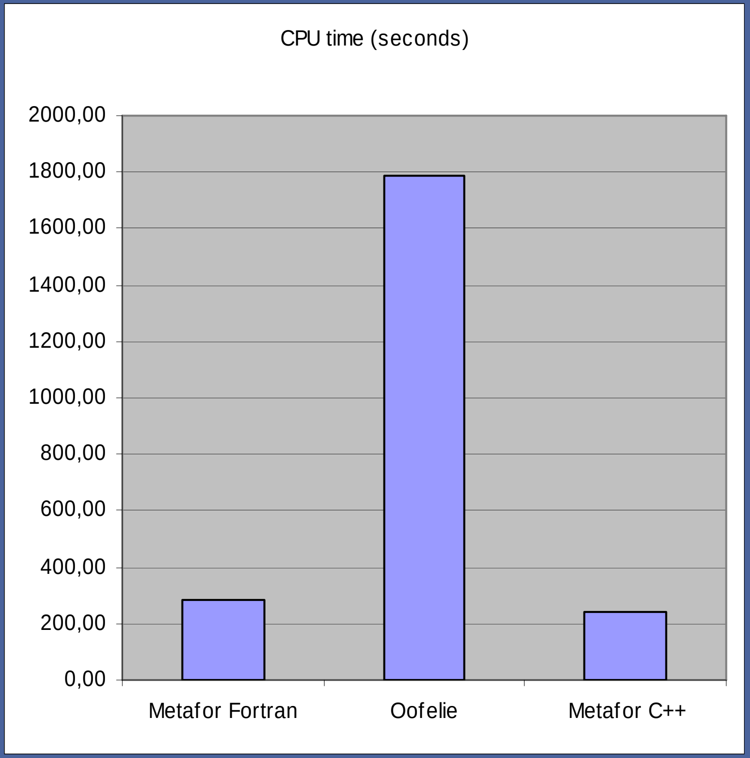
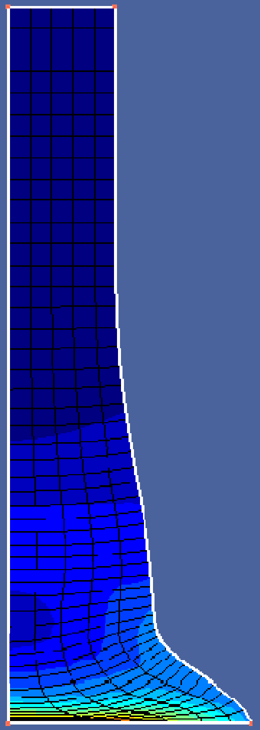
CPU-time optimizations

Code optimization - profiling

- C++ can sometimes be very slow if the programmer doesn't take care.
- A lot of work concerning Data Access & Memory Management optimizations has been done.





- Taylor bar impact (3D)
- Implicit integration scheme
- 240 elements - 399 nodes - 946 dofs

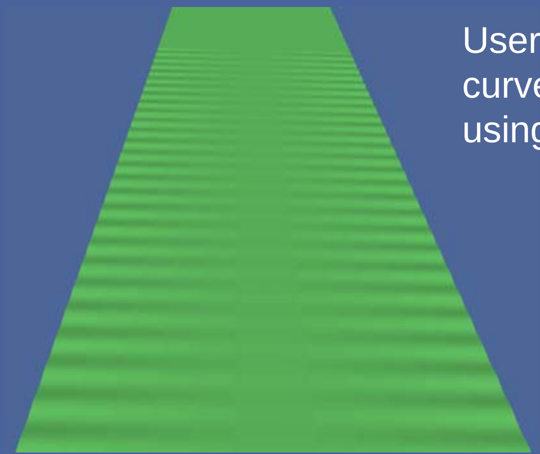
> Even faster than Fortran in this particular case!

> BUT still slower for explicit problems

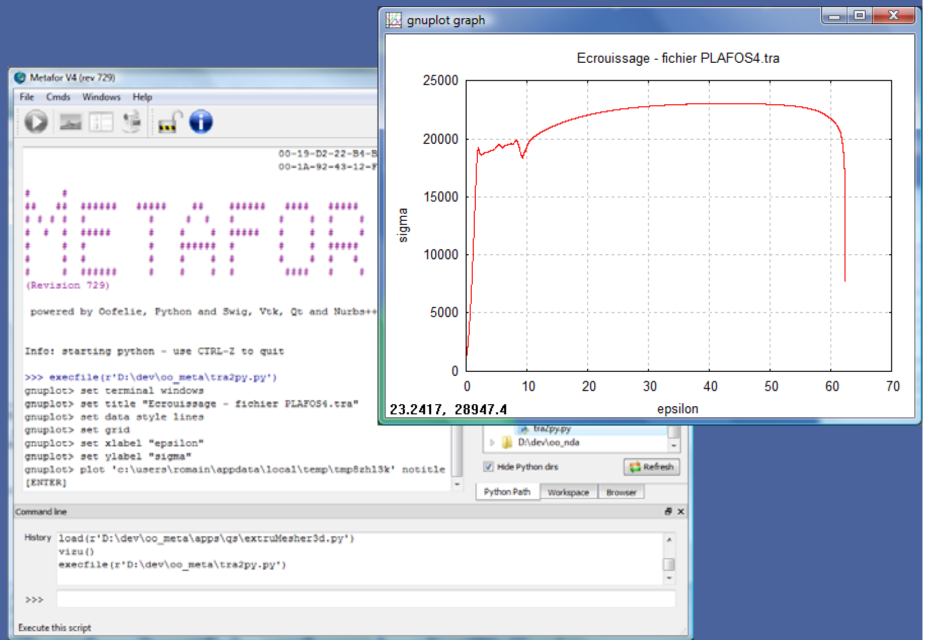
Python interpreter

Metafor & python

- Provides a command line (cfr Matlab)
- Avoids the use of an external preprocessing program / parser, etc
- Allows interpreted algorithms, user-defined materials, etc
- Through Python, Metafor can exchange data with GnuPlot, Matlab, etc
- …



User-defined geometric curve (sinusoïd) defined using a python script



Metafor running gnuplot

Numerical examples

1. Contact
2. Thermomechanics
3. Material laws
4. Integration schemes
5. ALE formalism

Contact

1. Shock damper device (2D)
2. Deep drawing (S-Rail)
3. Shock damper device (3D)
4. Drawbead (Nine's test)
5. Skin pass
6. Tube Hydroforming
7. Roller levelling (3D)

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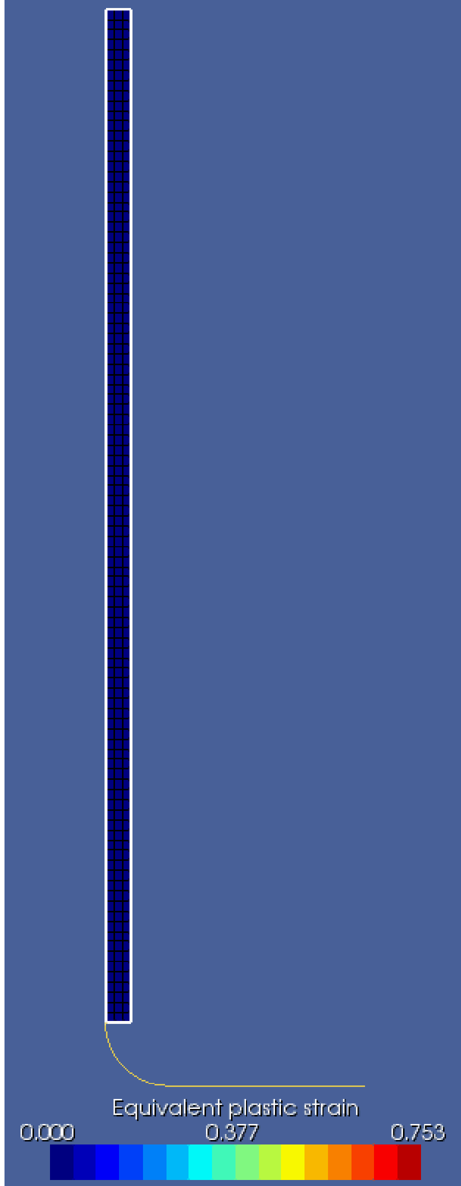
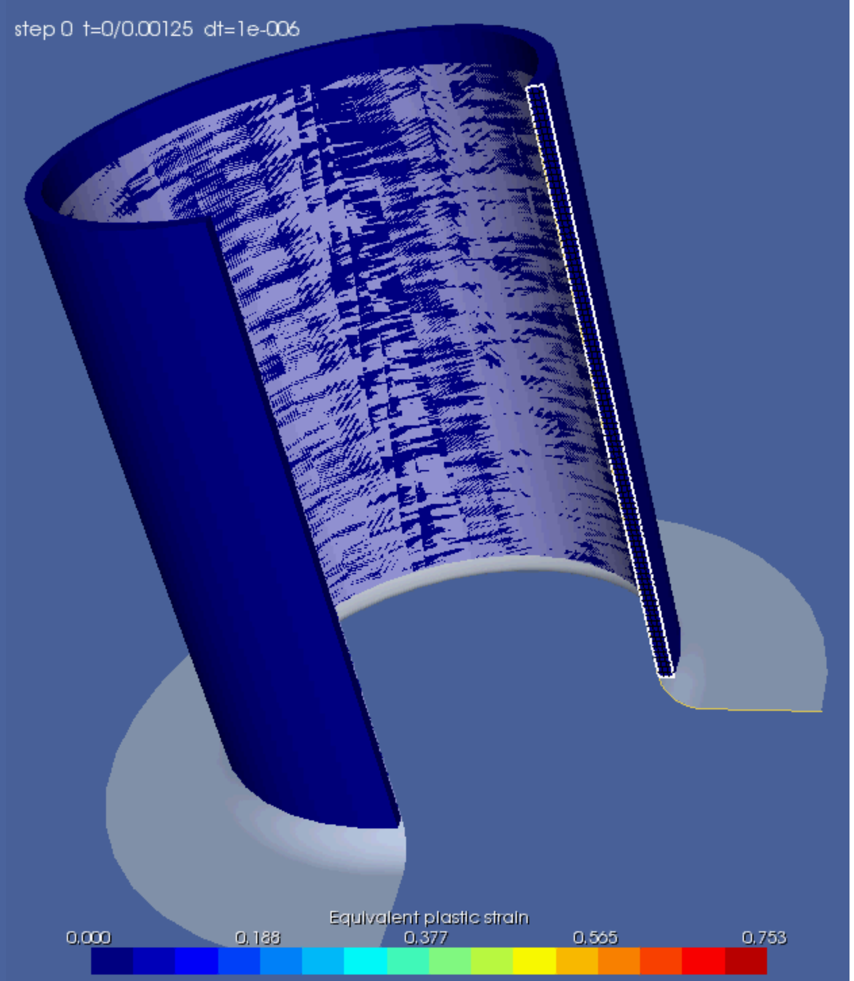
2D contact

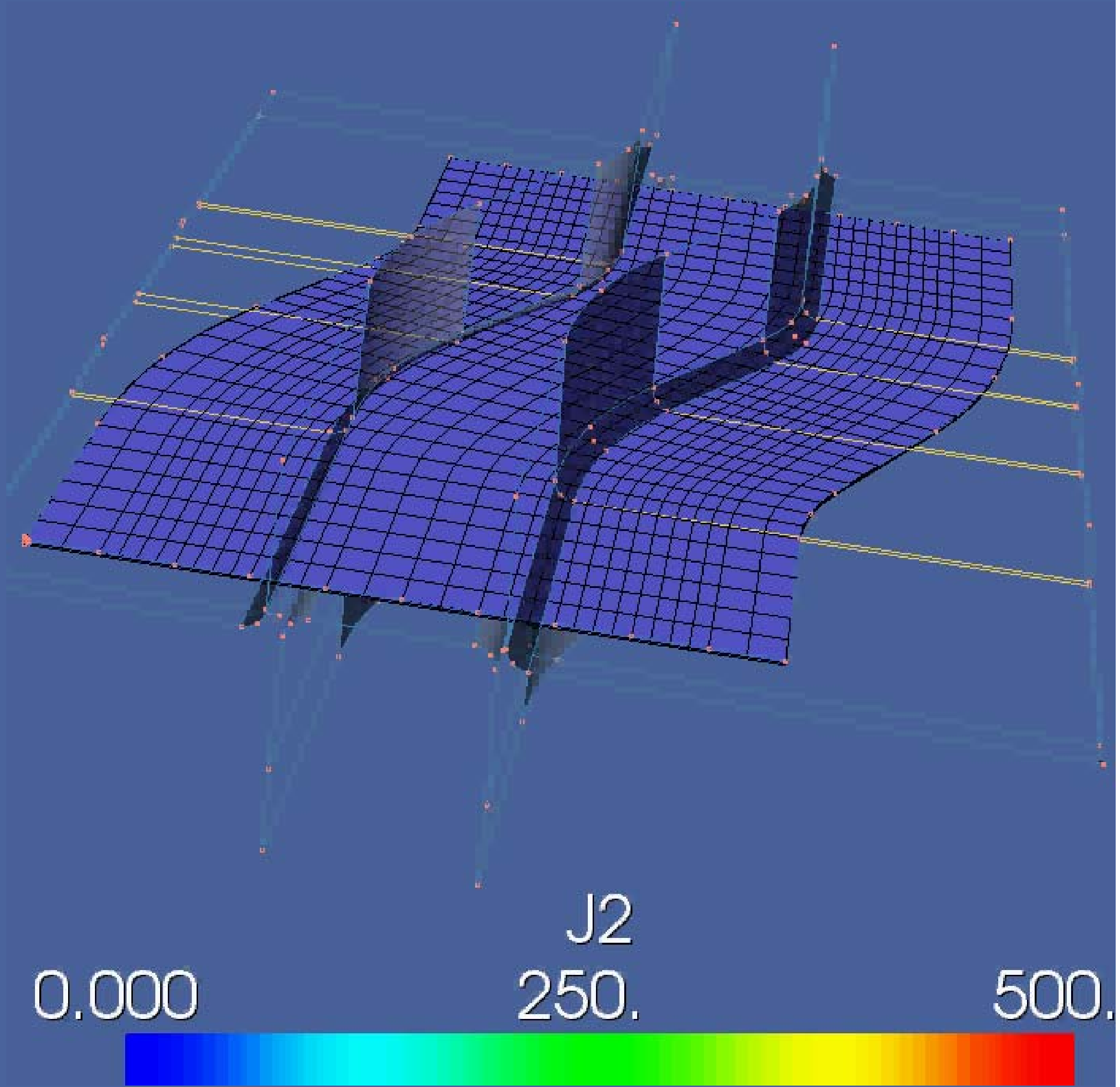


- Thermomechanical simulation of a cylindrical shock damper device
- The problem is 2D axisymmetric
- The penalty method is used for managing contact between the metal and the rigid die

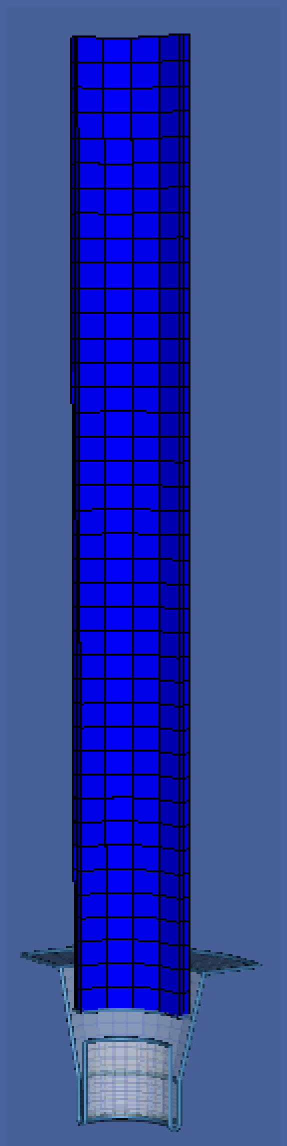


S-Rail benchmark

(Numisheet '96)

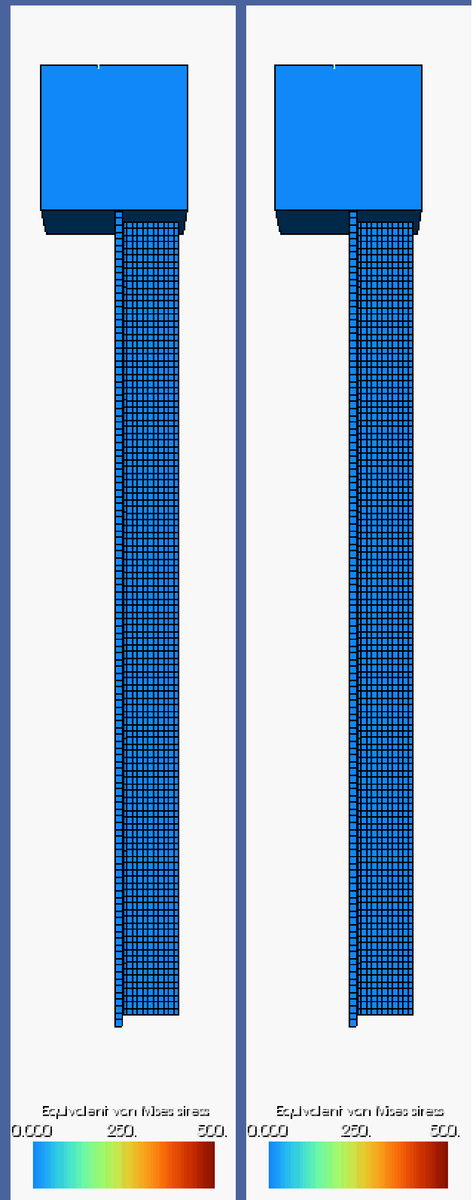


- Deep drawing of an "S-shaped" rail.
- The die and the punch are rigid.
- Friction is taken into account between the tools and the blank.
- Springback is computed removing the tools and using an implicit scheme.



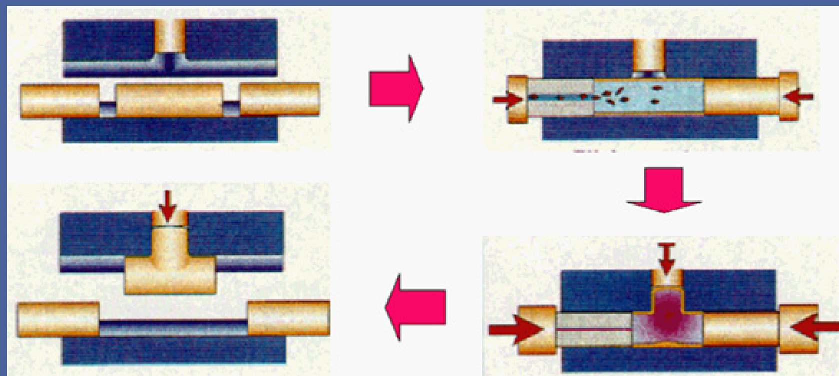
Contact between deformable bodies

- 3D Simulation of the dynamic buckling
- Contact between non smooth surfaces (resulting from discretisation).
- Friction is taken into account between the die and the cylinder.



Hydroforming of a tube

- Thermomechanical hydroforming of a tube.
- Material with thermo-elastoplastic behavior.
- The exact geometry of the die has been imported from CATIA (including Nurbs surfaces).



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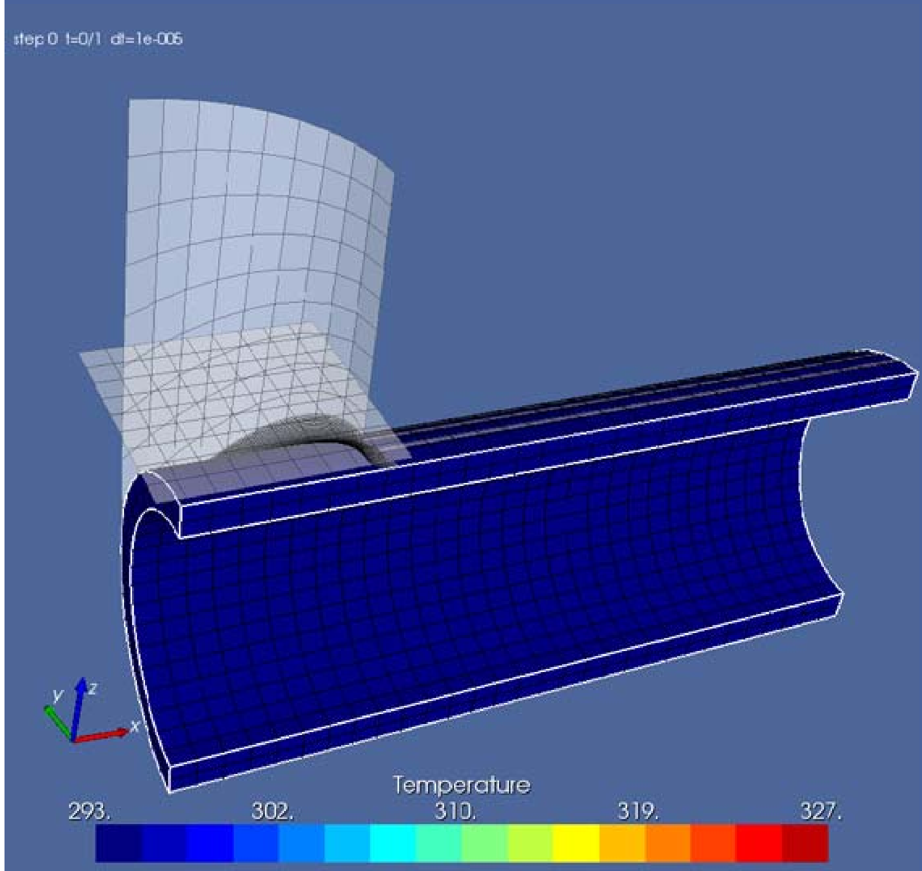
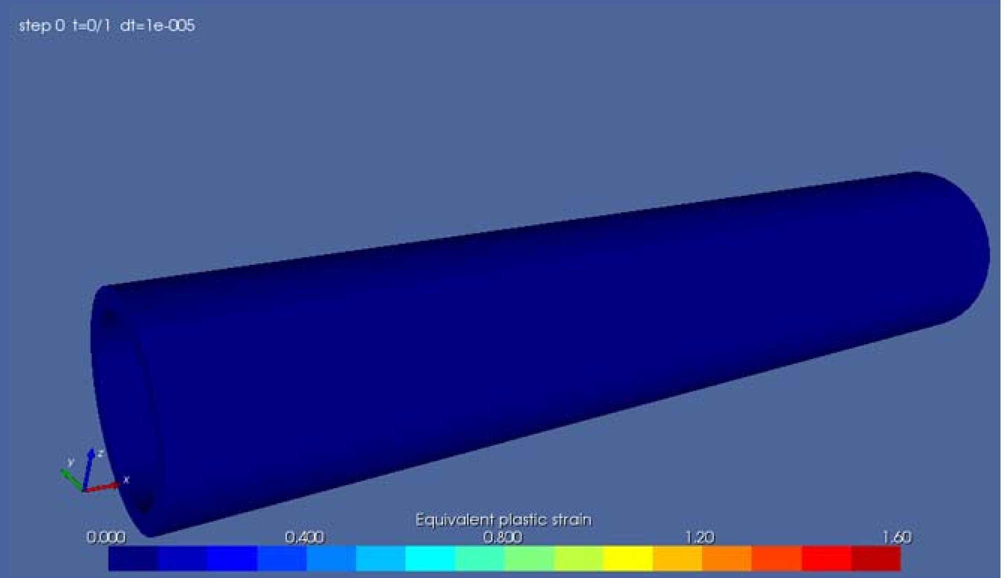
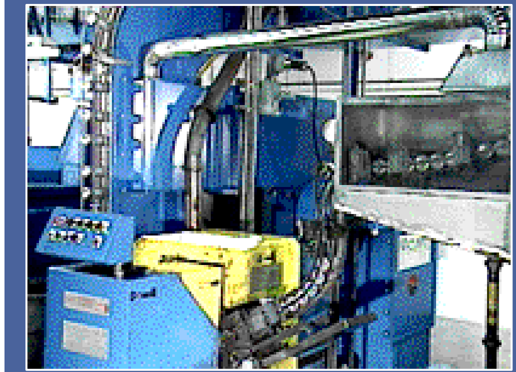
Hydroforming of a tube

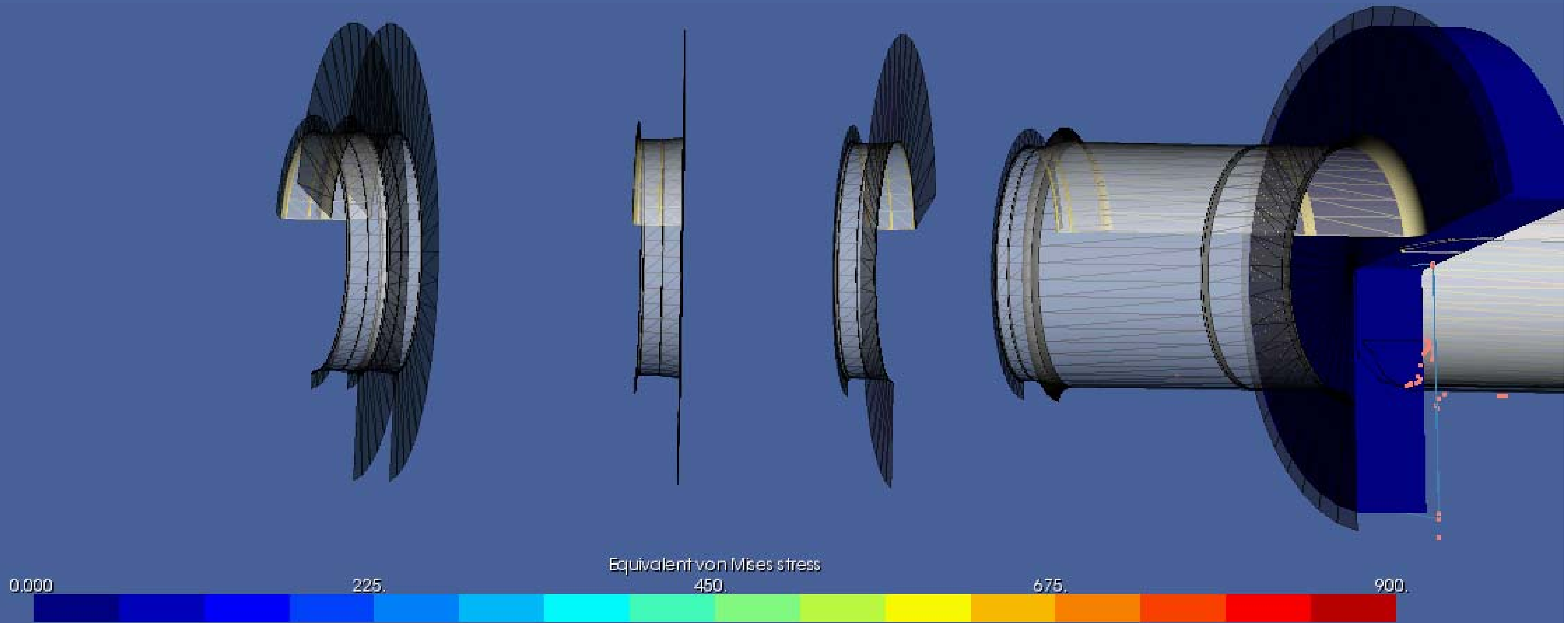




Drawing & Wall Ironing



- Simulation of can manufacturing
- High speed process : 200 cans/min

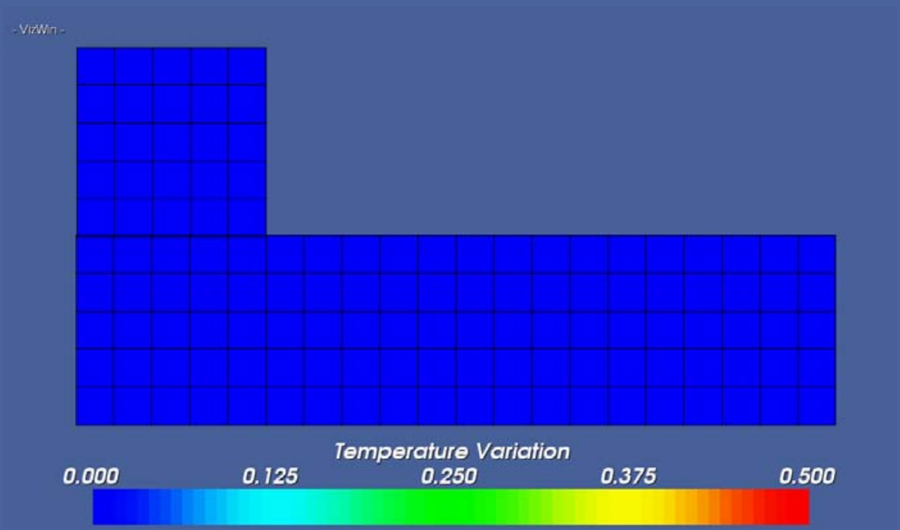


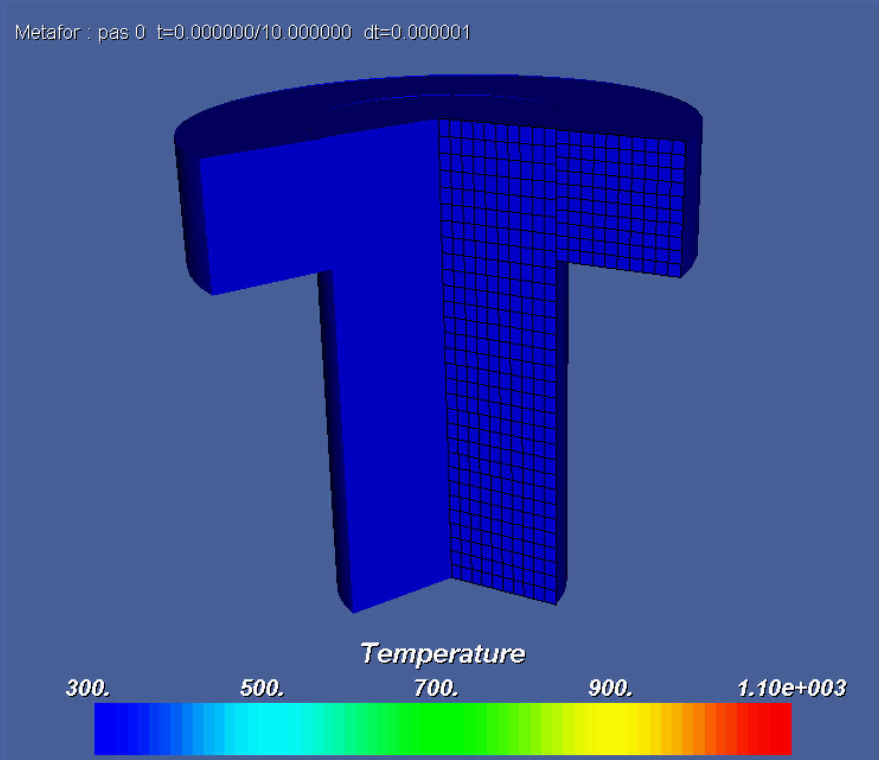
Thermomechanics

1. Thermocontact
2. Rivet forming

Thermomechanical contact

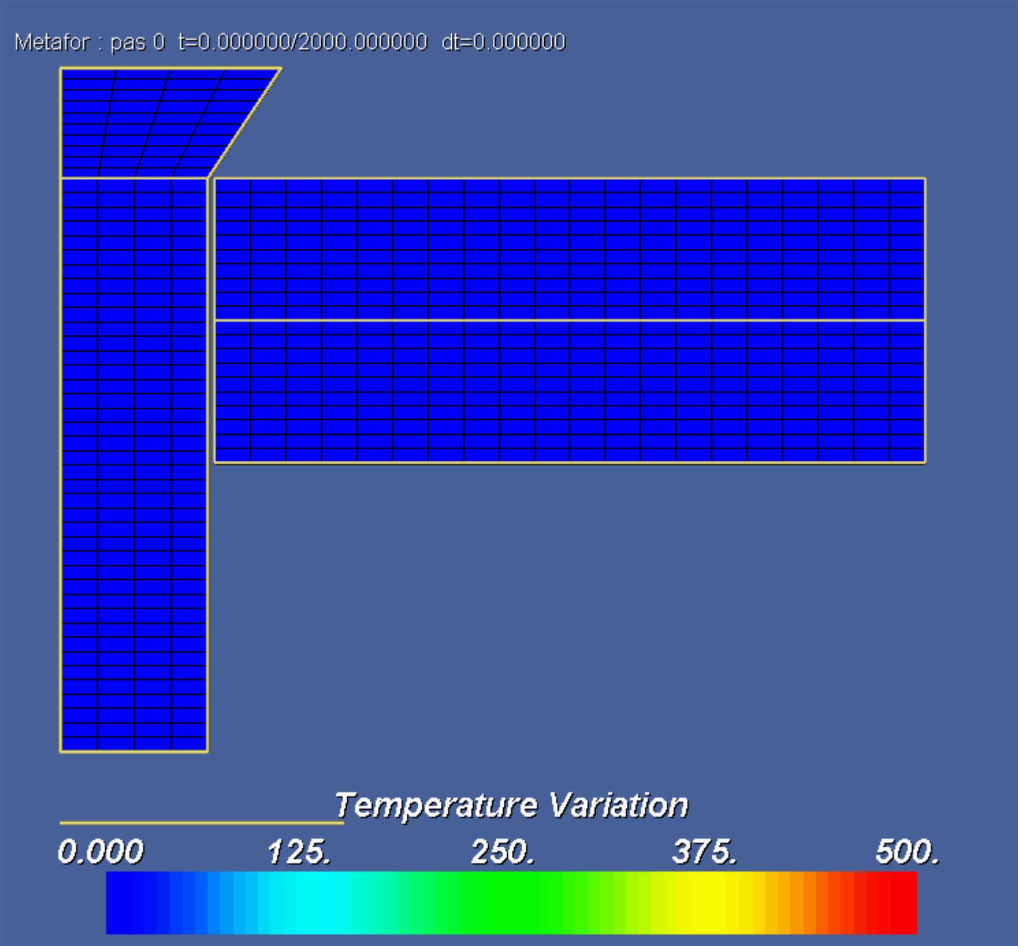
- Thermocontact interactions between two sliding blocks (no heat transfer with the environment).
- Two phases process :
  - Fast sliding inducing heat generation.
  - Homogenization of the temperature field by heat transfer through the contact interface.
- Initial temperature 300 K. Final homogenous temperature 300.75 K.





➢ Initial temperature 300 K. Final homogenous temperature 399.8 K.

Rivet forming



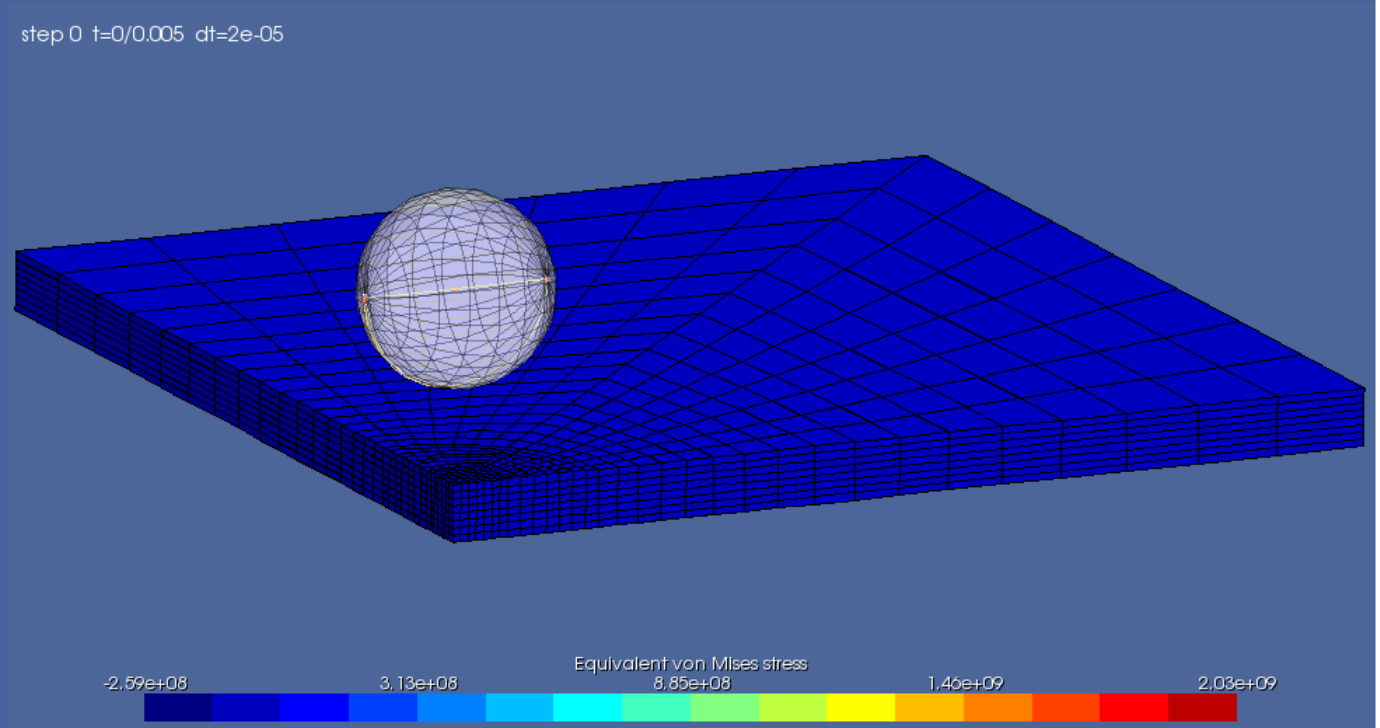
- Thermomechanical forming of a rivet for plates assembly.
- Material with thermo-elasto-viscoplastic behavior.
- Elastic, plastic and viscous behaviors are temperature dependent.
- Computation of the viscoplastic dissipation.
- Thermocontact interactions between the two plates and the rivet.
- Computation of the exchanged heat fluxes and of the frictional dissipation.

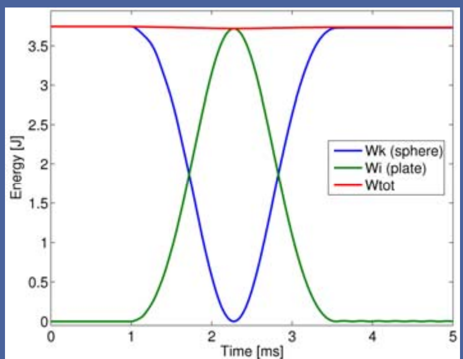
Material laws

1. Superplastic forming (tee)
2. Superplastic forming (elbow)
3. Propagation of crack
4. Fast tensile test with damage and fracture
5. Buckling of blade in LP compressor
6. Thixoforming

Composite materials

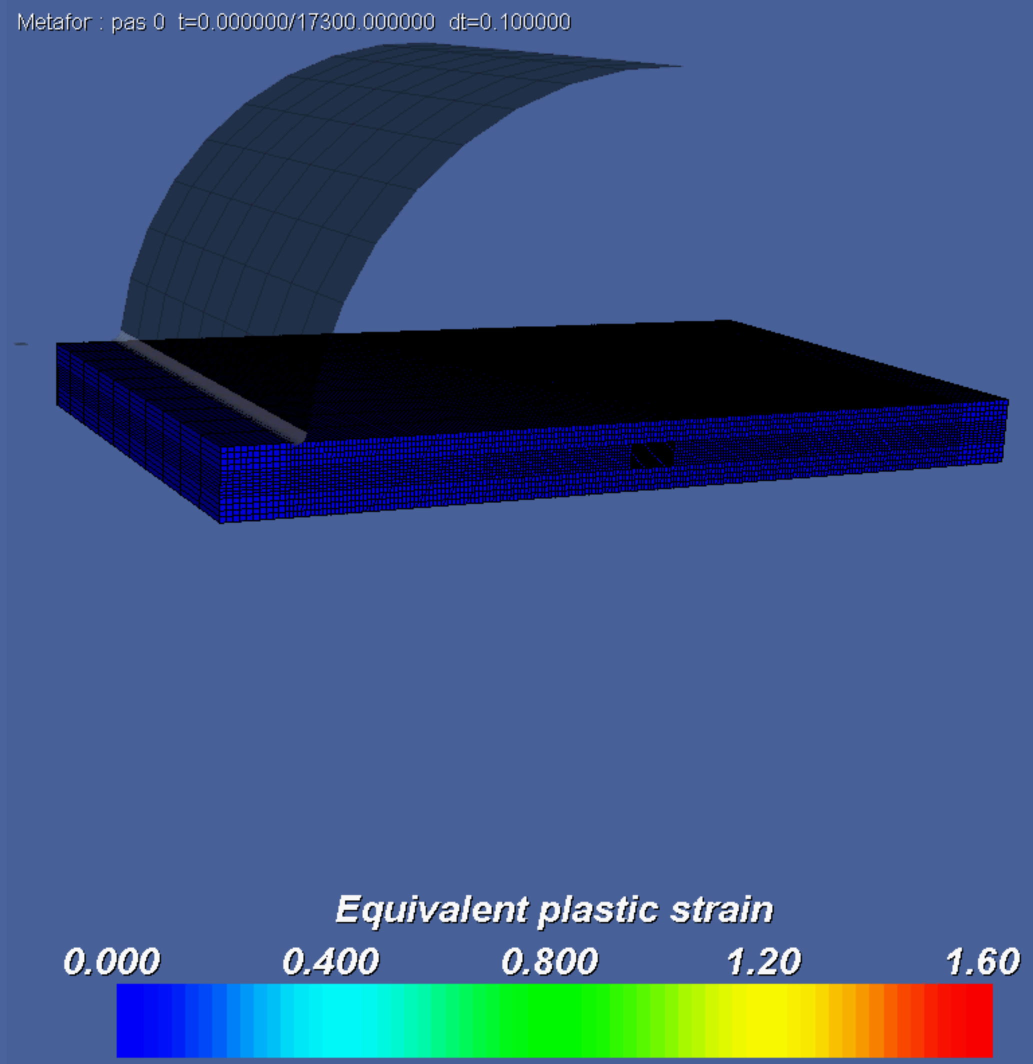
- Framework: “Avion+Composites” project
- Simulation of the impact of a spherical projectile (1cm) on a weaved multi-layered sheet of composite material
- Material is linear elastic / 1 element per layer
- Energy conservation is verified



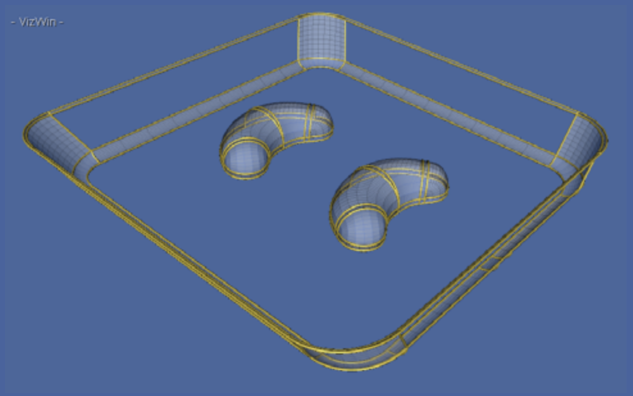


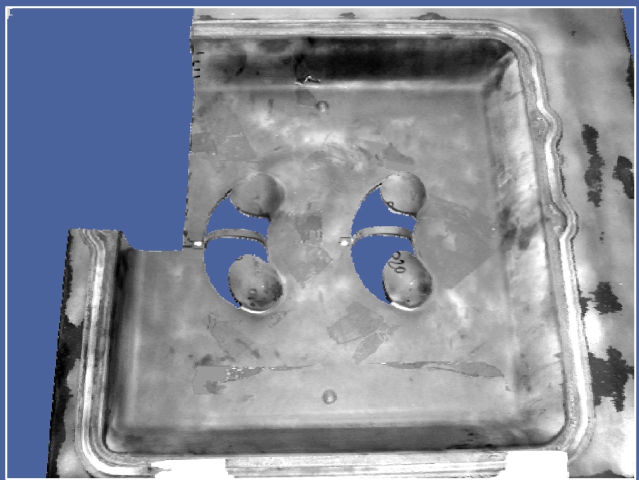
Superplastic forming

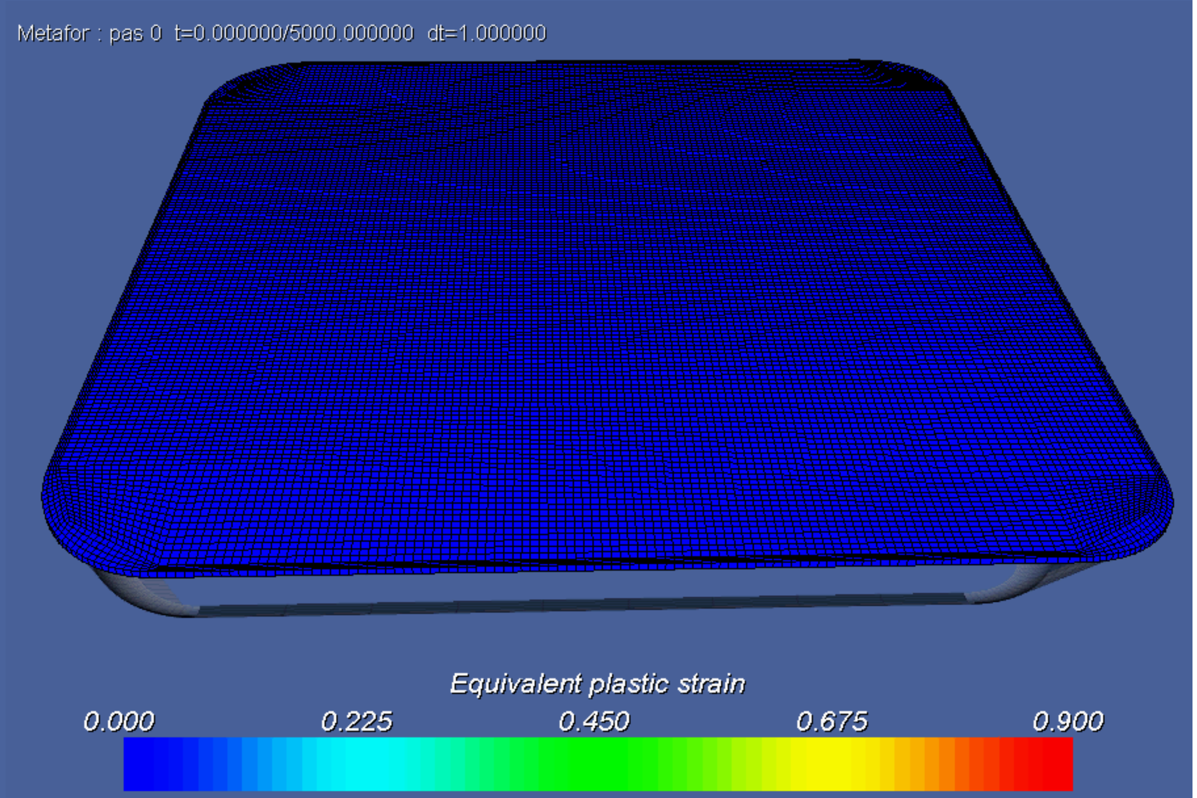
- Multisheet superplastic forming of a self-stiffened structure (Sonaca).
- Optimal pressure cycle is computed in order to stay below a given plastic strain rate.



Superplastic forming

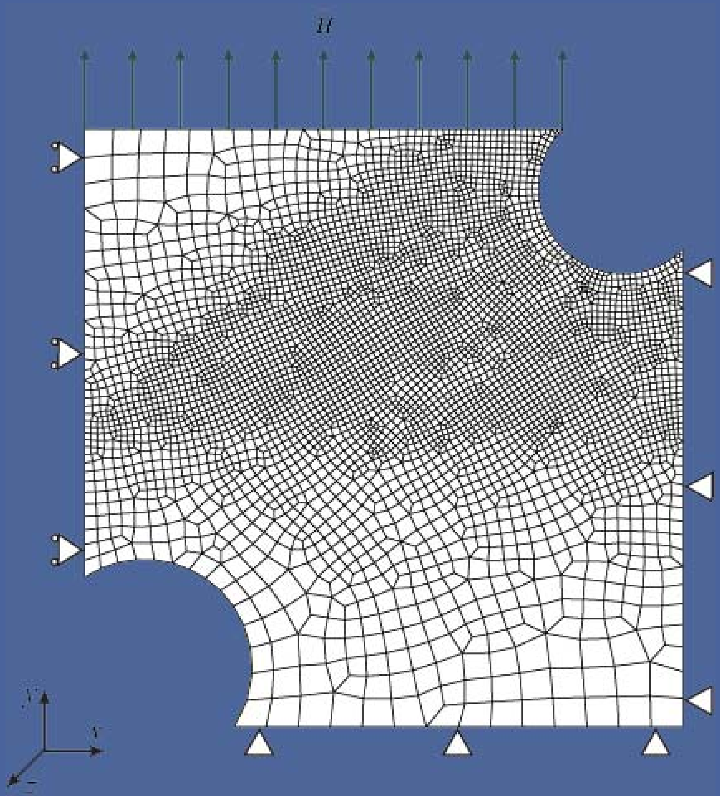


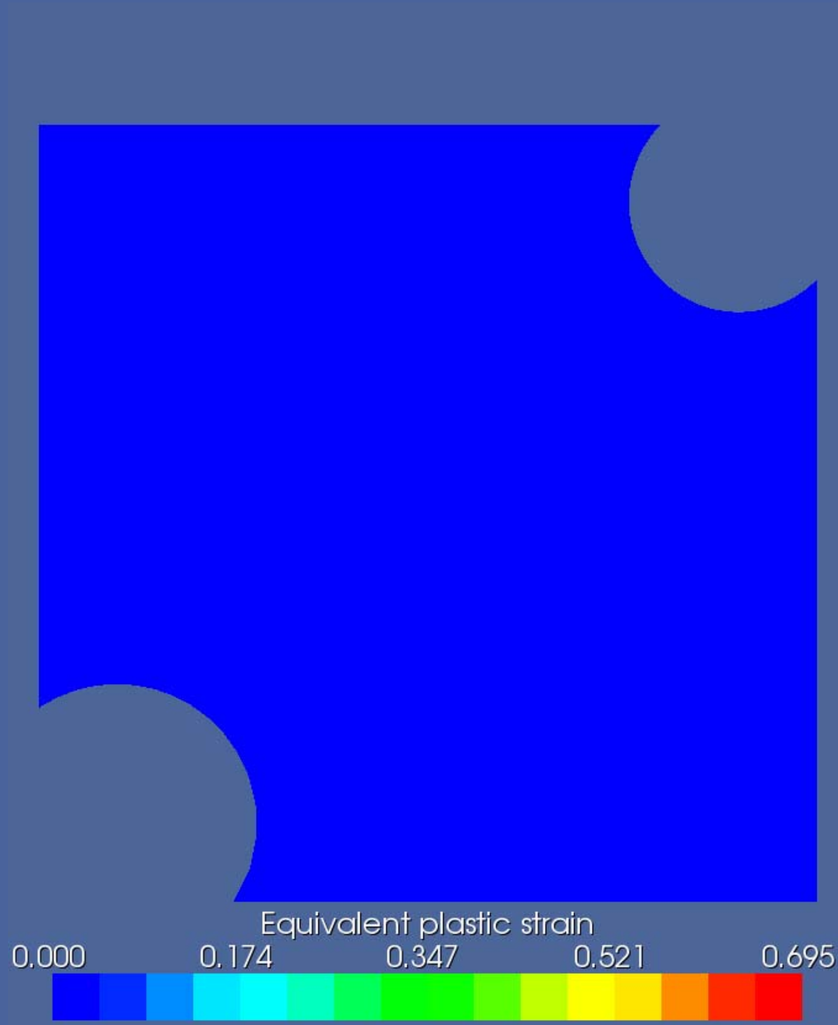




- Importation of an industrial geometry including NURBS curves & surfaces.
- Superplastic Forming (coarse mesh) with optimization of the applied pressure cycle.

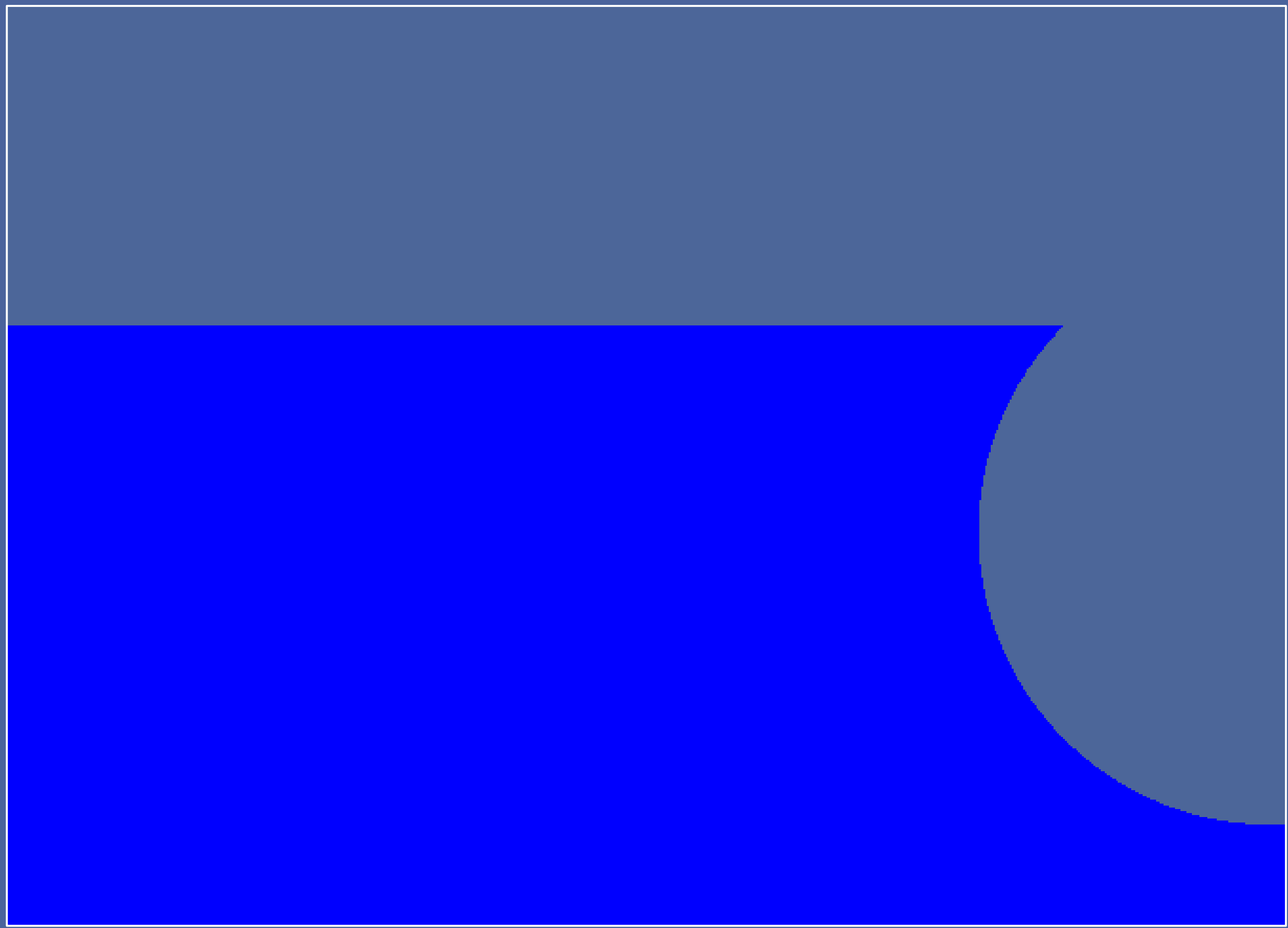
Propagation of a crack



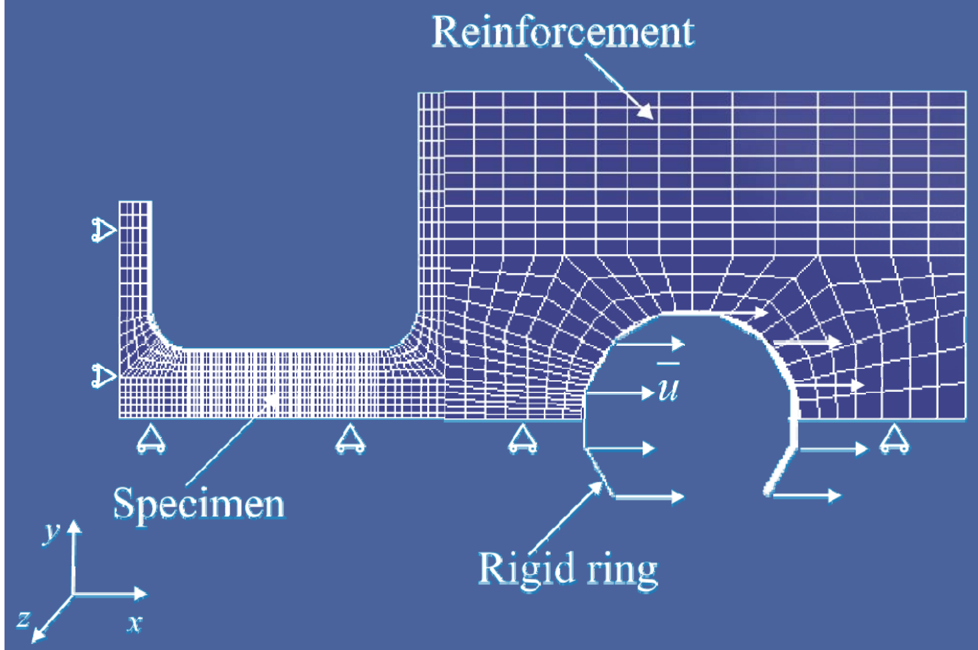


- Traction test of double notched specimen.
- Erosion method to model material fracture
- Quasi-static process.

Propagation of a crack

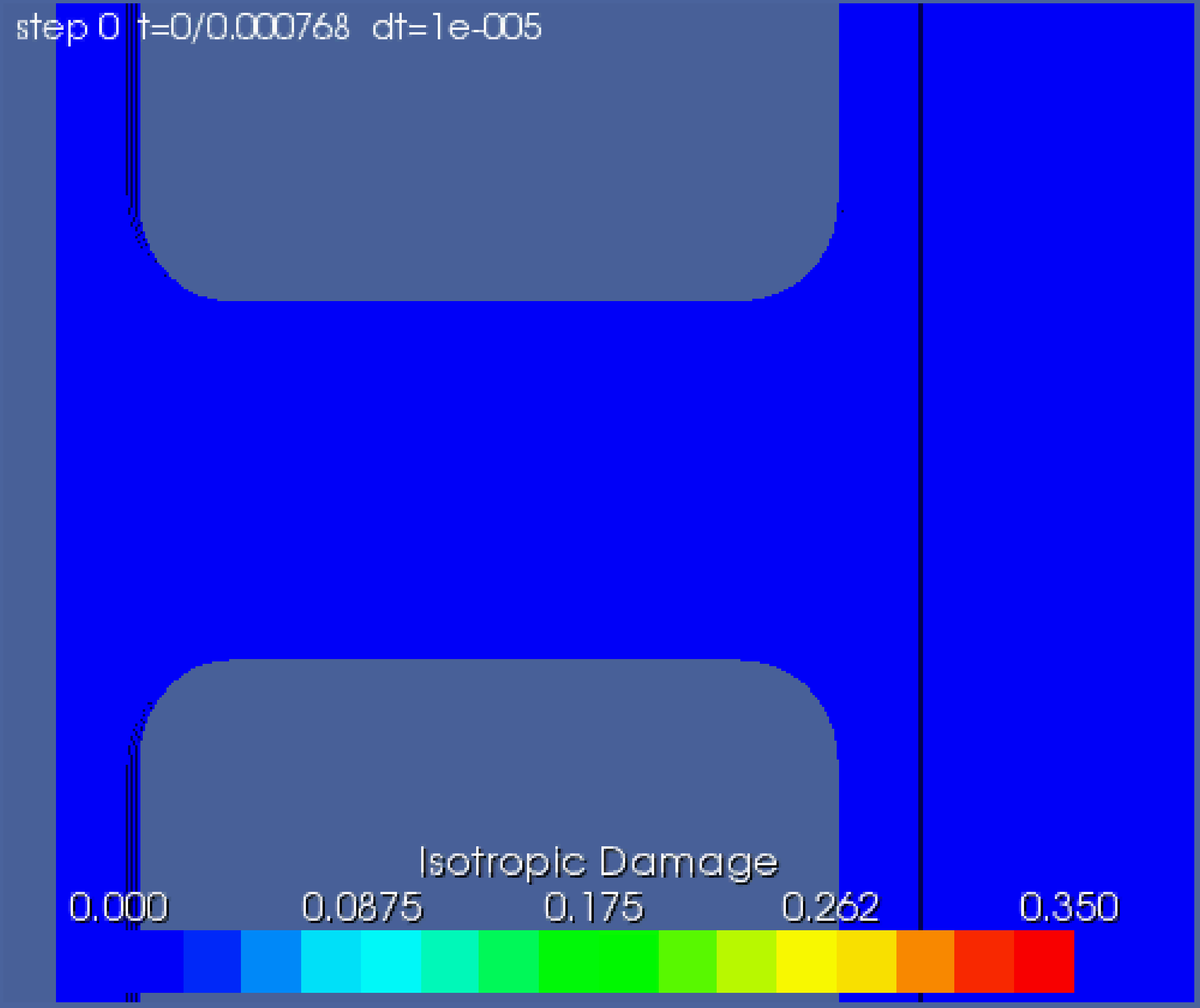


Fast tensile test with damage and fracture

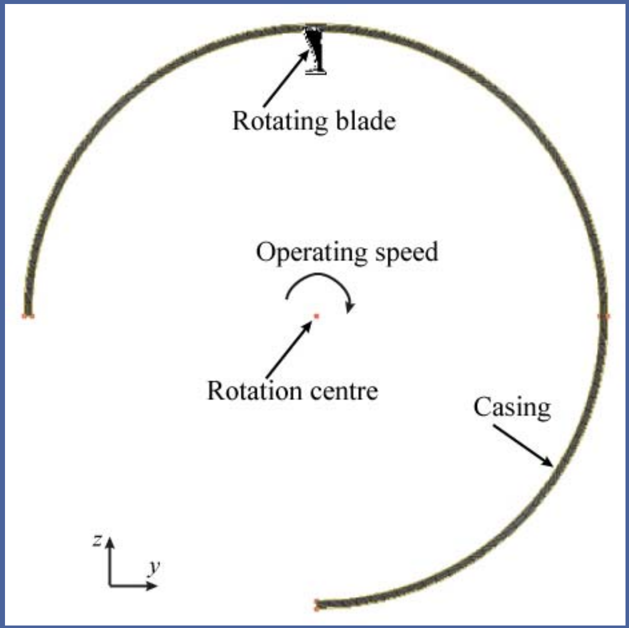


- Simulation of a fast tensile test.
- Material: high strength steels (TRIP and dual phase)
- Thermomechanical implicit algorithm.
- Material model with dynamic material laws.
- Damage of material modelled with continuum damage mechanics
- Erosion method to model propagation of fracture.
- In collaboration with Prof. Salima Bouvier (Laboratoire des Propriétés Mécaniques et Thermodynamiques des Matériaux - Paris)

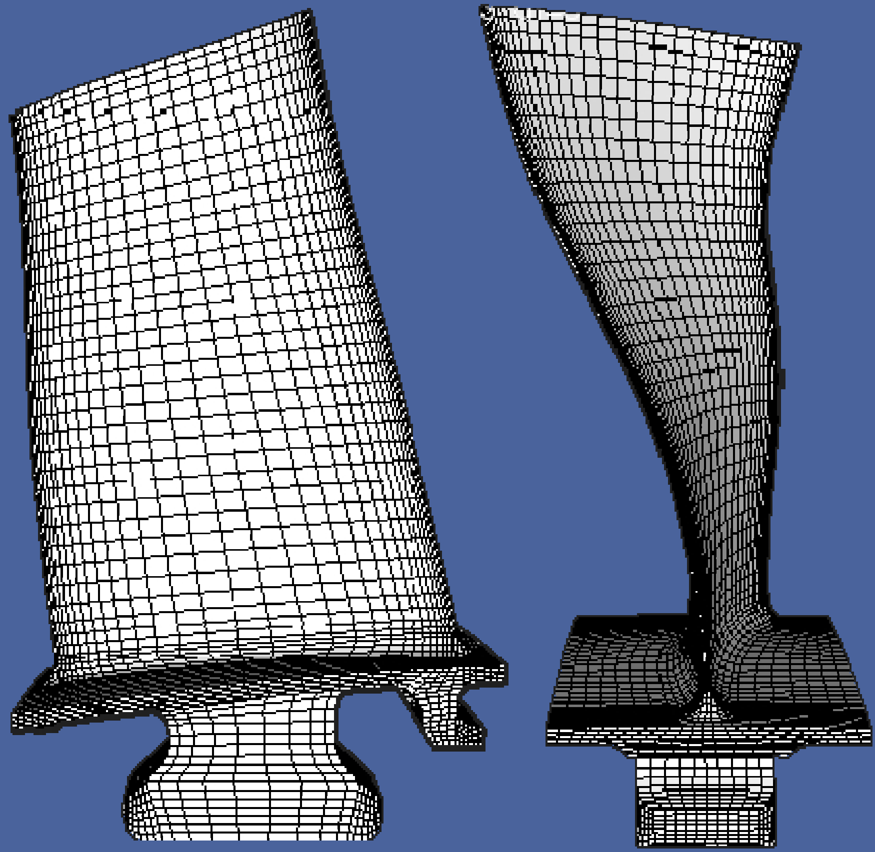
Fast tensile test with damage and fracture



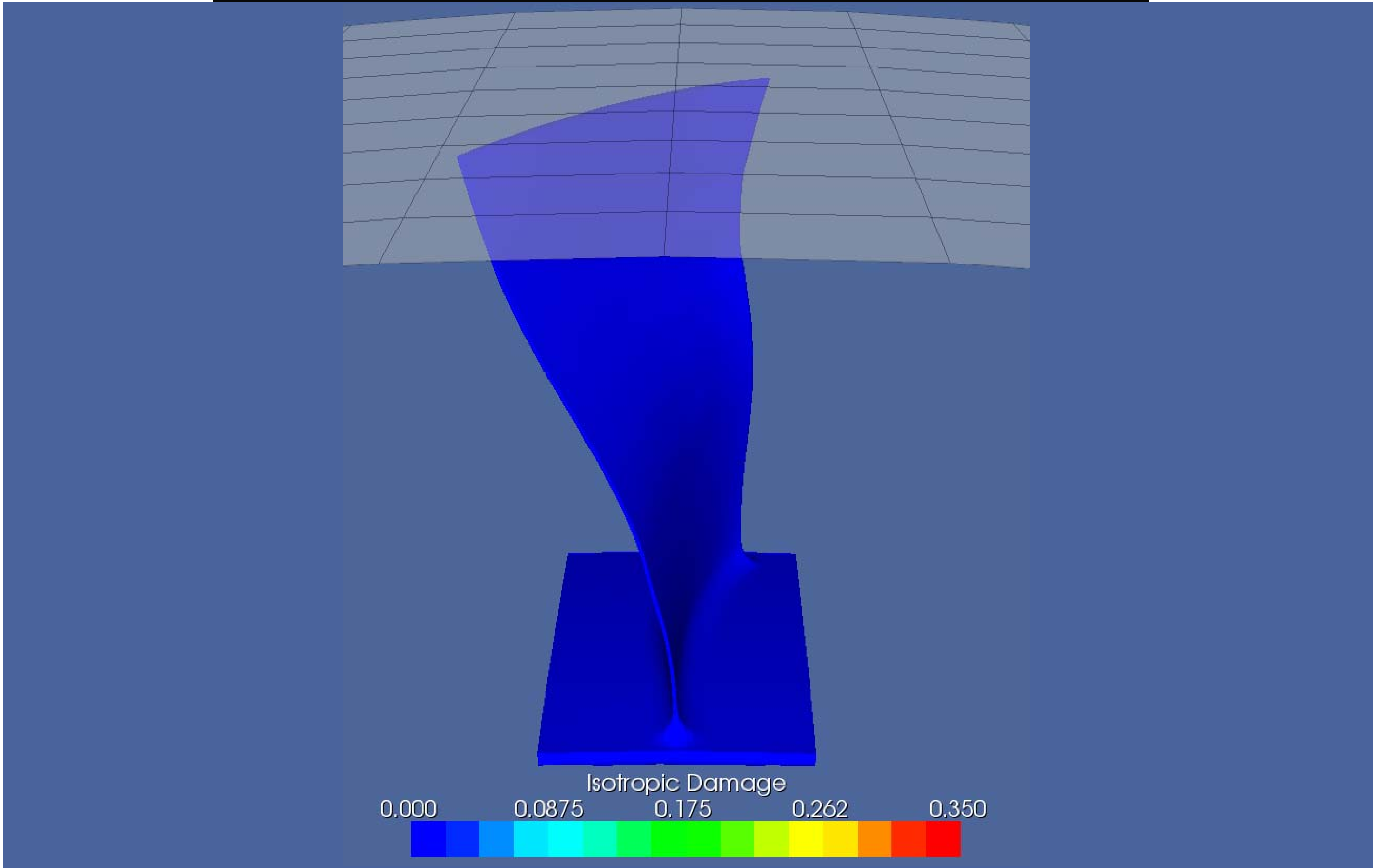
Buckling of blade in LP compressor



- The casing suddenly moves off centre
- Thermomechanical implicit algorithm
- Material model with damage
- EAS finite elements, 18h CPU-time

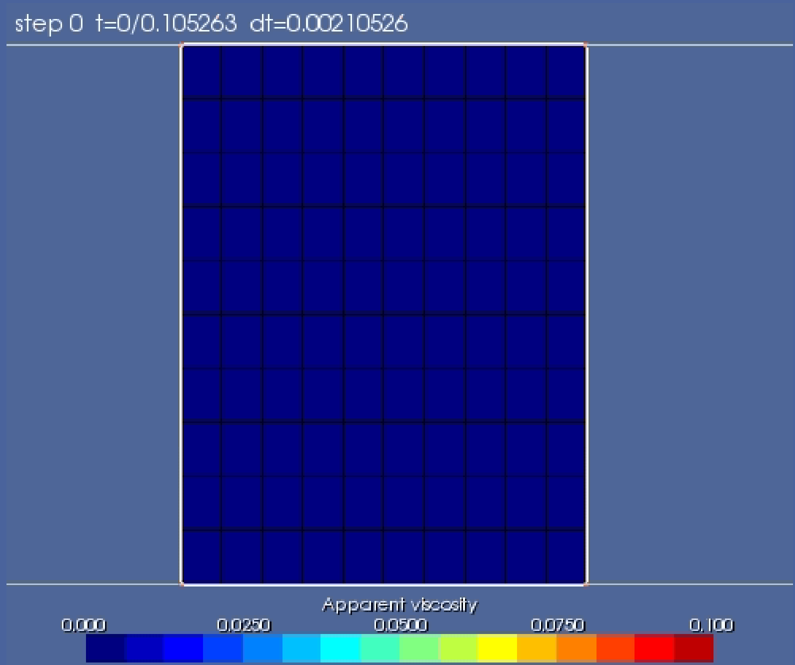


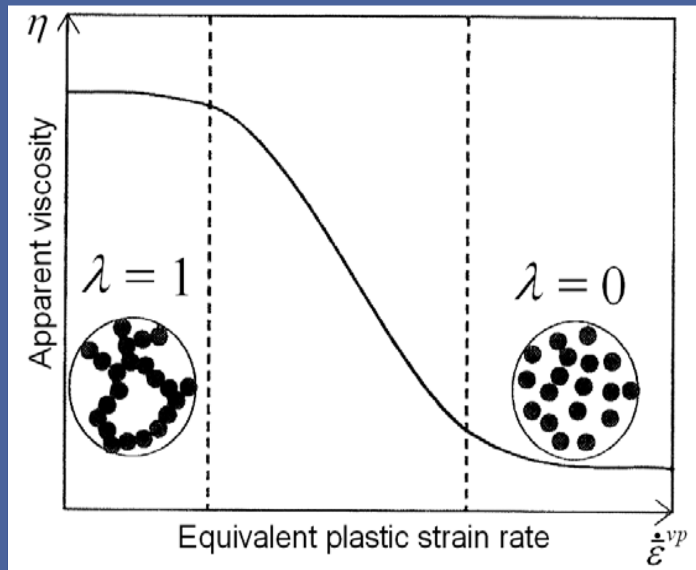
Blade geometry is meshed by ICEM3D


Isotropic Damage
0.000
0.0875
0.175
0.262
0.350

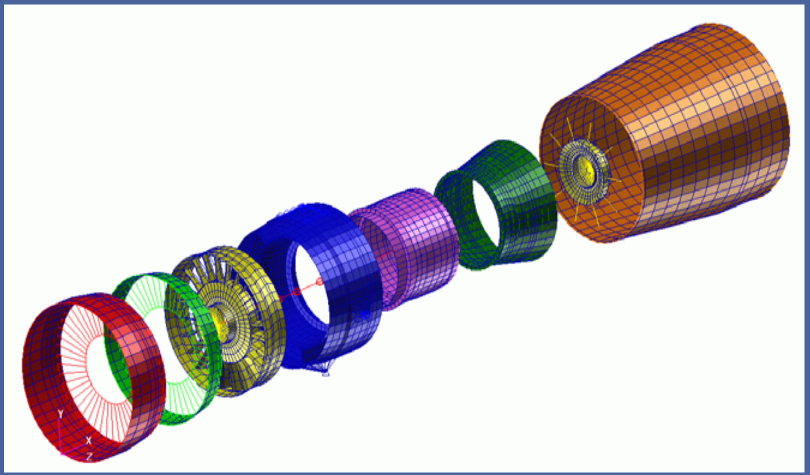
Thixoforming

- Semi-solid (SS) thixoforming is a forming process at temperatures located inside the fusion interval
- Combines the advantages of casting and forging
- First validation: Compression test of a cylinder (Kang & Yoon, J. Mat. Proc. Tech., 1997)



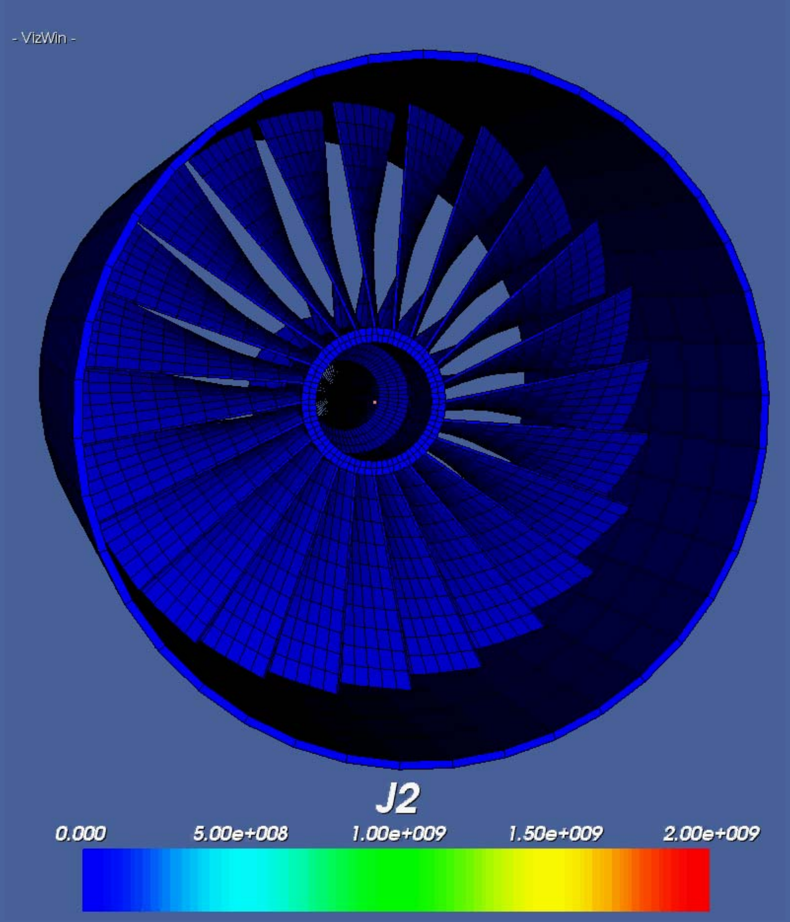


Fan Blade containment test

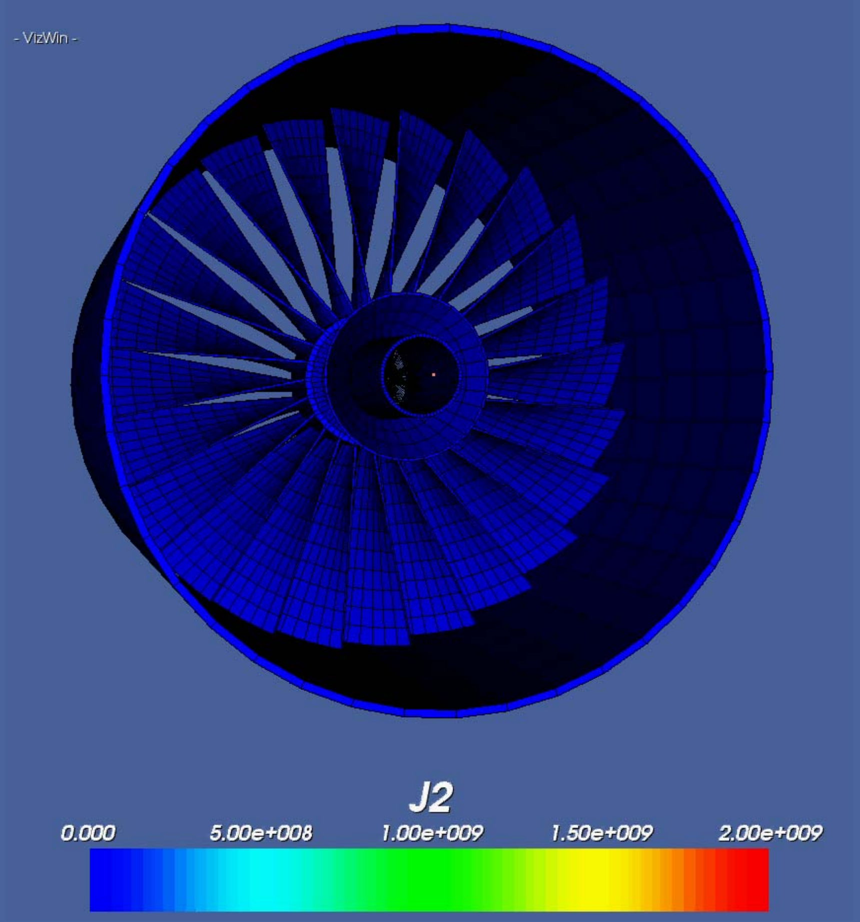


- Numerical simulation of an engine validation test
- Implicit algorithm (CPU time : 50h – ev6 600MHz)
- (fixed) bearing & (moving) shaft connected by springs
- Blade/casing frictional contact interactions

Blade-loss simulation



Front view

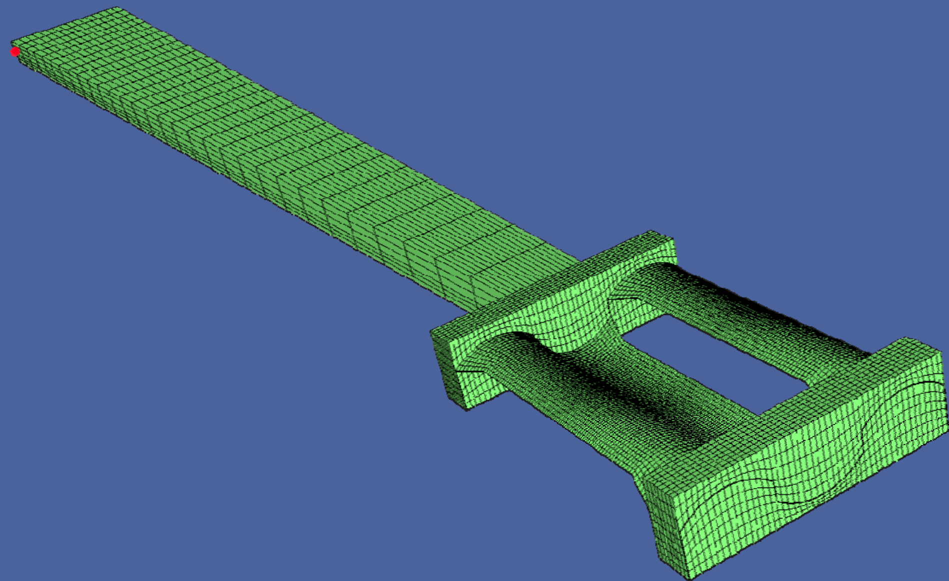


Rear view

Dynamics of a “Maeva” hinge

(TFE B.Desauvage 2007-08)

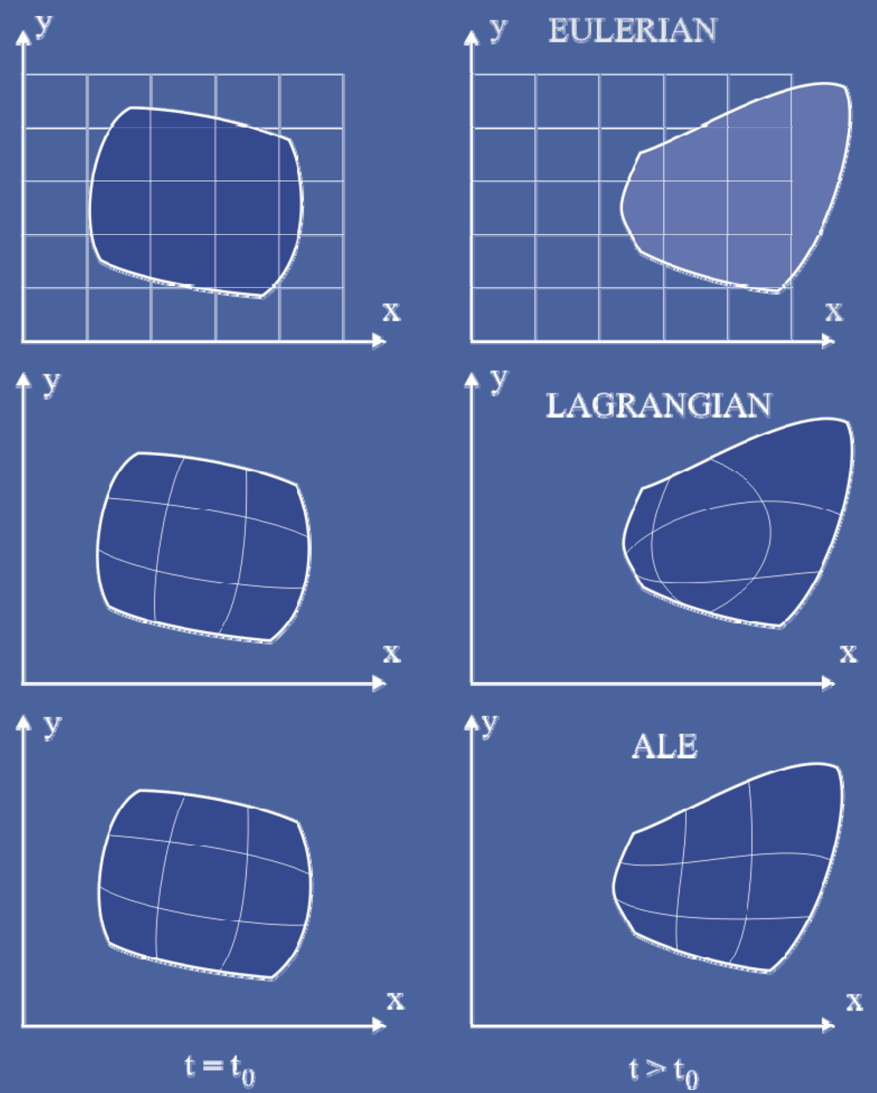
- Framework: Student Space Exploration and Technology Initiative (SSETI) - ESA
- ESEO project (European Student Earth Orbiter) : micro-satellite conception
- Spread out of a satellite hinge (made of Carpentier joints) for solar panels deployment



ALE formalism

1. Introduction
2. Operator split
3. Convection schemes
4. Rezoning methods
5. Contact with friction

Introduction



EULERIAN FORMALISM

- ✔ Undistorted mesh
- ✔ Ideal for stationary processes
- ✖ Free boundaries are difficult to follow

LAGRANGIAN FORMALISM

- ✔ Free boundaries are computed automatically
- ✔ History dependant materials are easier to handle
- ✖ The mesh can be rapidly distorted
- ✖ Large amount of finite elements are needed for the simulation of stationary processes

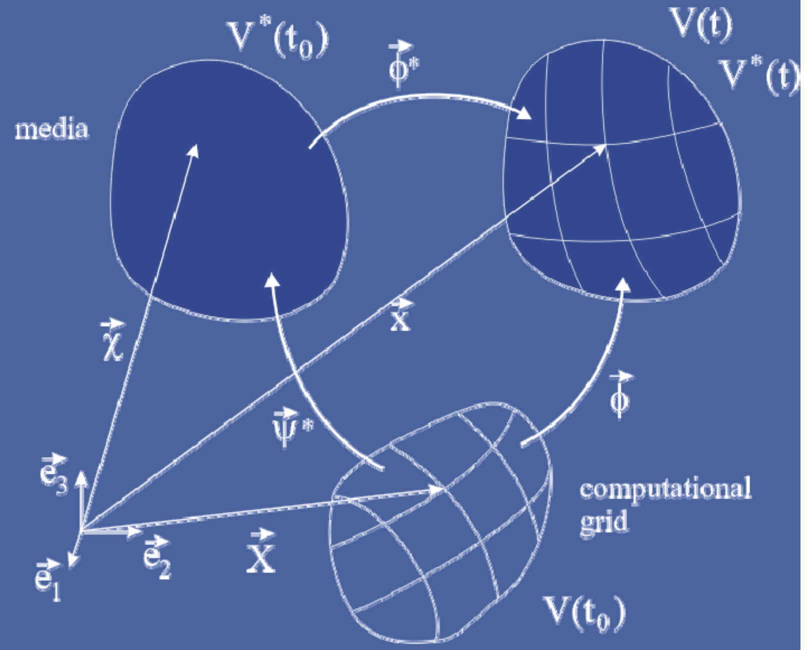
ALE Formalism – Operator Split

Complex problem

2 coupled problems :

- Equilibrium of the body in motion
- Motion of the mesh (minimization of distortion,…)

→ too complicated & too slow



Simplified problem

Time increments are divided into 2 steps :

- **LAGRANGIAN STEP**

  (Same as in Lagrangian formalism)

- **REMESHING & CONVECTIVE STEP**
  - Body is remeshed
  - Values stored at the Gauss points/nodes are updated

$$\left.\frac{\partial A}{\partial t}\right|_X = \left.\frac{\partial A}{\partial t}\right|_\chi + \vec{w}\cdot\vec{\nabla} A$$

$\vec{w} = \vec{v} - \vec{v}^*$: relative velocity

$\vec{v}$: material velocity

$\vec{v}^*$: mesh velocity

ALE applications

1. Coining
2. Wire extrusion
3. Extrusion
4. Machining
5. Rolling
6. Roller leveling
7. Roll forming

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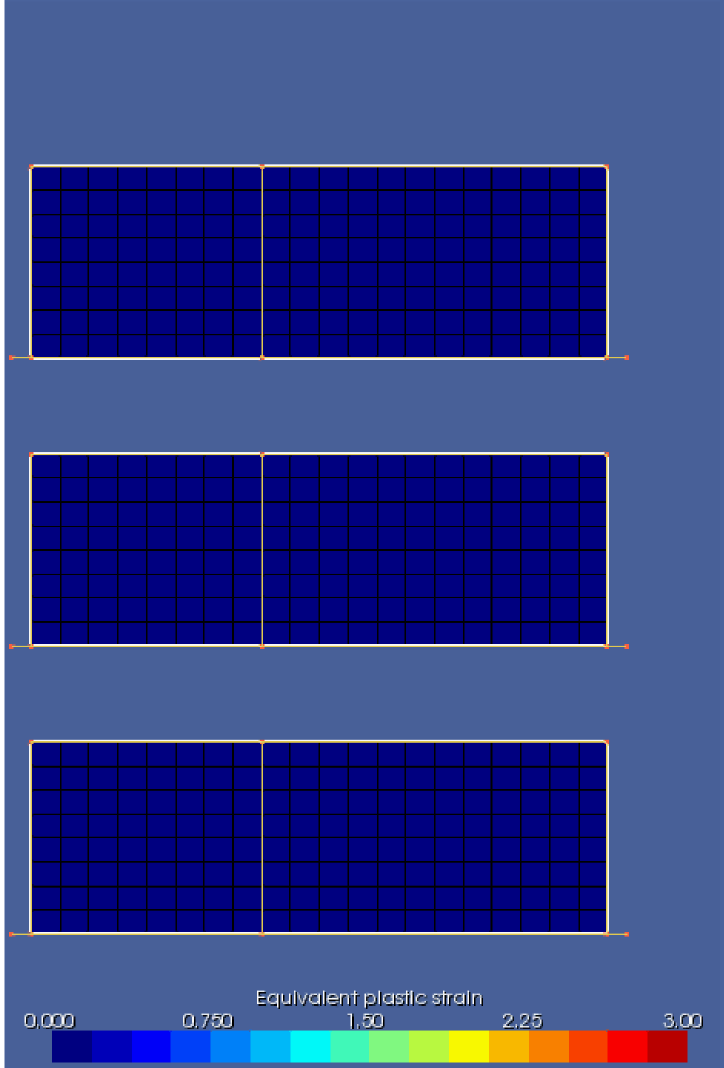
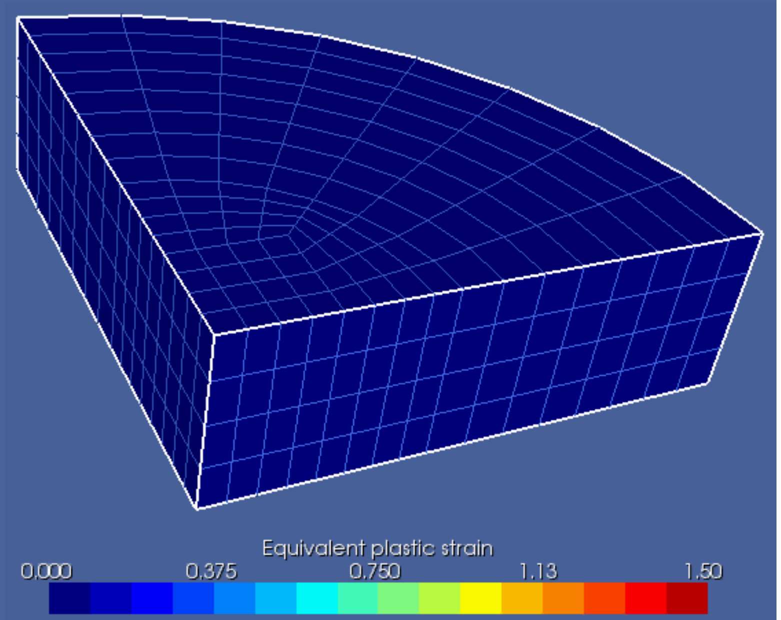
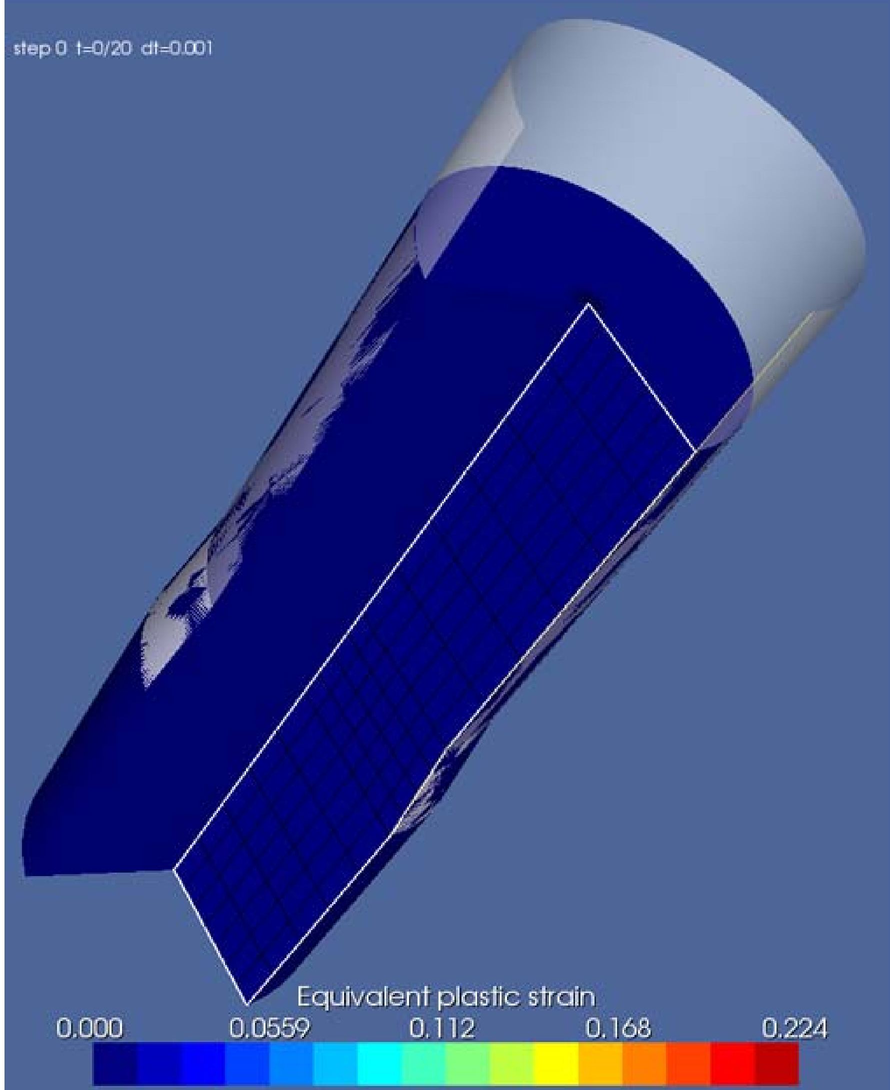
Coining of a cylindrical block using ALE



- ALE formalism is used for avoiding mesh distortion
- Upper boundary nodes are constantly moved on the free surface to keep the boundary curved shape
- Height of the workpiece is reduced by 60%
- Results must be axisymmetric

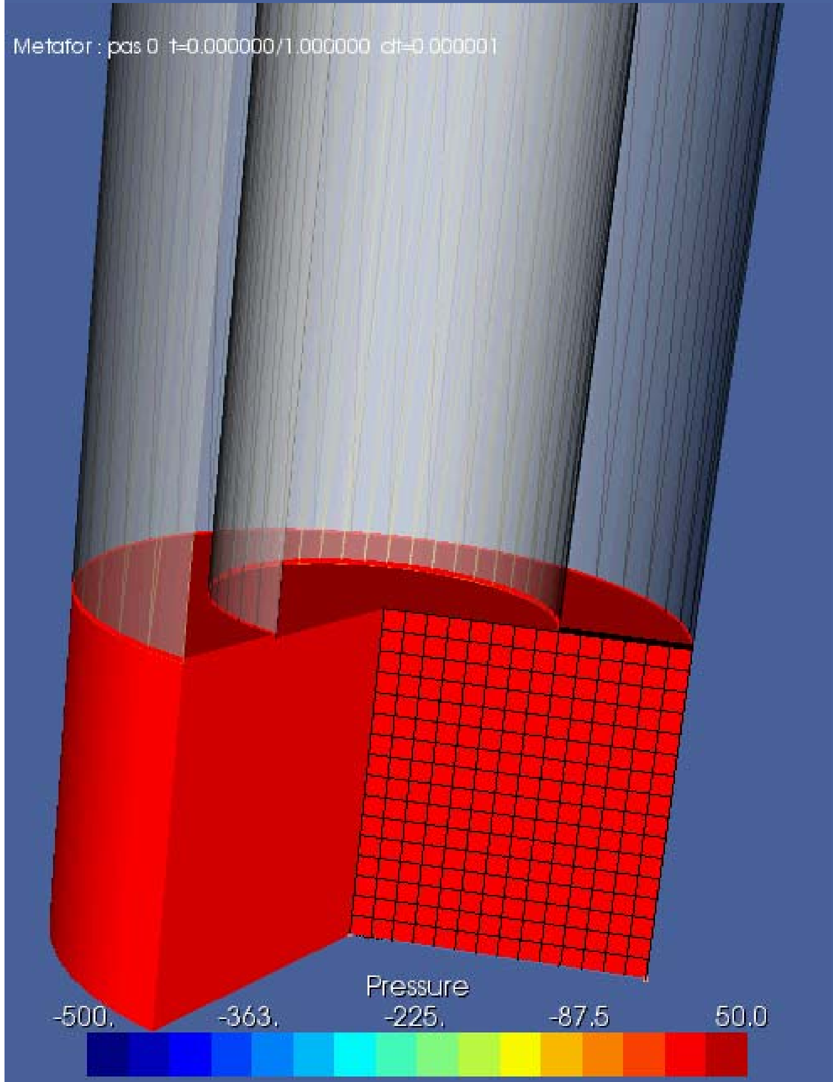


Stationary wire extrusion using ALE formalism

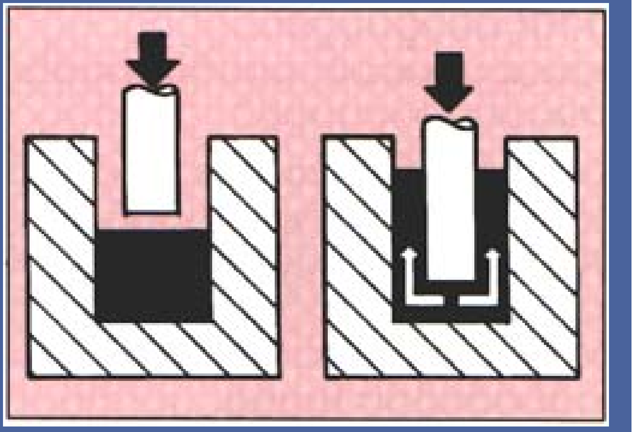


- The ALE formalism is used for simulating this stationary process.
- The mesh is Eulerian (every nodes are moved back to their initial position after each step). This avoids to consider a very large Lagrangian mesh.
- The problem is axisymmetric.
- The wire is pulled from the top through a rigid die.
- The penalty method is used for the contact between the die and the wire.
- After a brief transient state, the stationary state is reached.

Backward extrusion using ALE

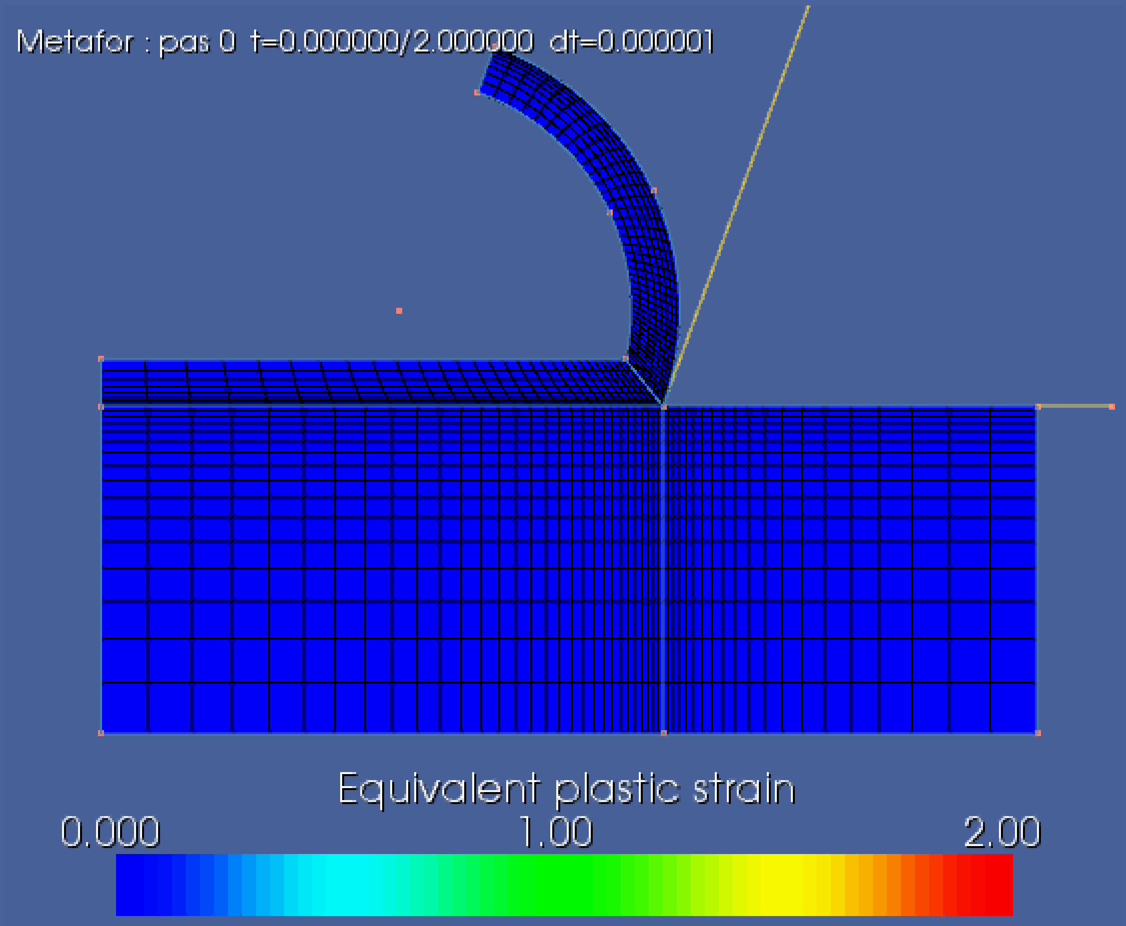


- A cylindrical piece of metal is pushed through a rigid tool.
- A very thin mesh is placed where the solid is supposed to go out.
- During the process, this flat mesh grows due to the convection and the main mesh shrinks.
- The shape of the mesh remains good and no remeshing is needed.

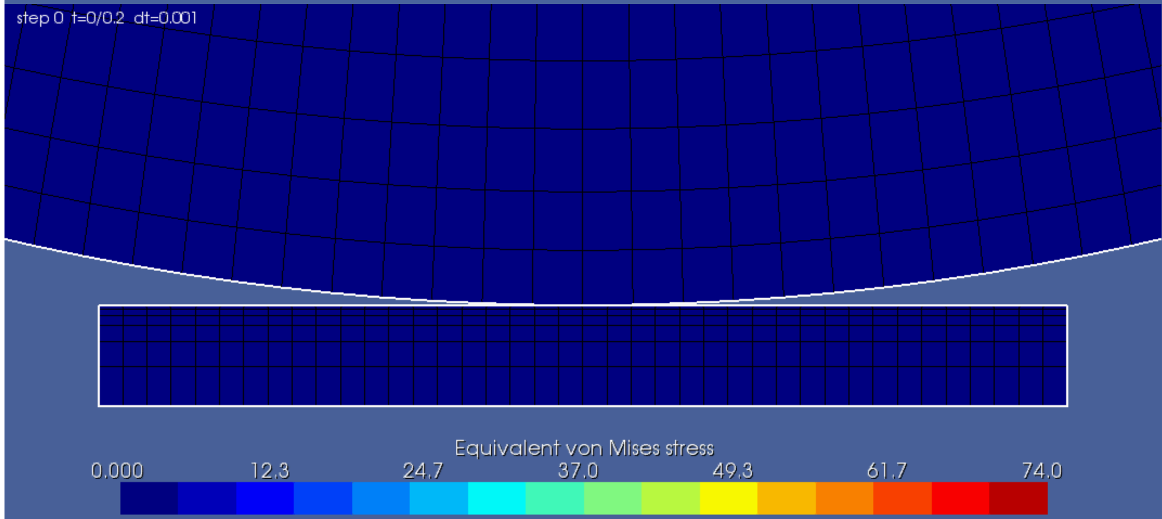


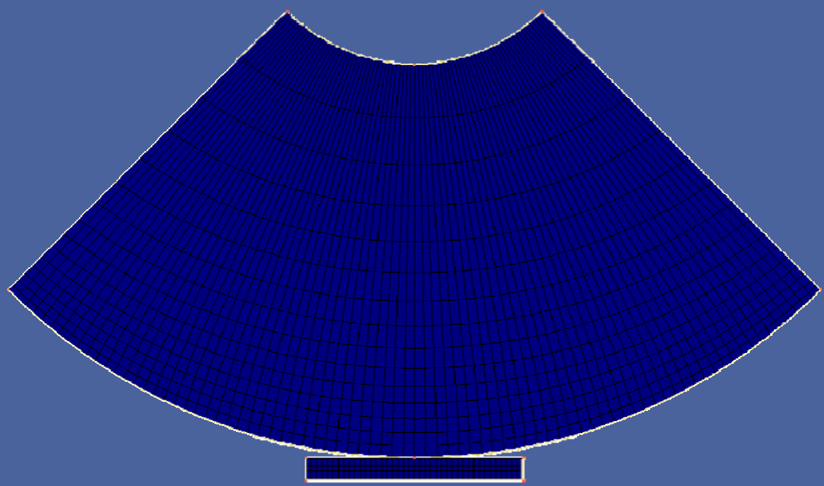
Machining using ALE

- A tool cuts and divides a piece of metal into two parts
- A guess of the final stationary shape of the chip is used as initial mesh.
- The final shape (chip's width) is automatically computed by the ALE method
- The mesh is refined near the crack.
- The model could be highly improved with an appropriate cracking model.



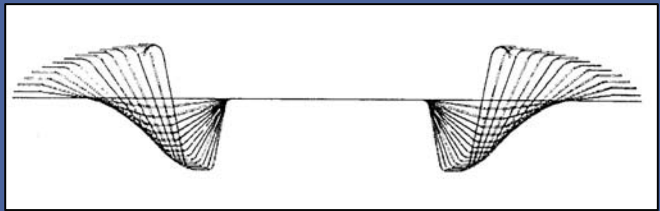
Cold Rolling process using ALE formalism

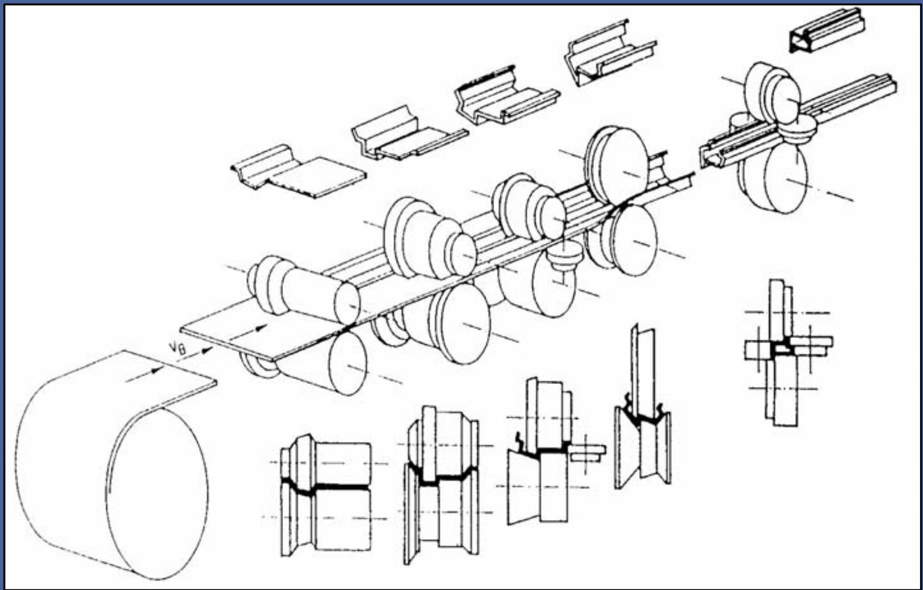


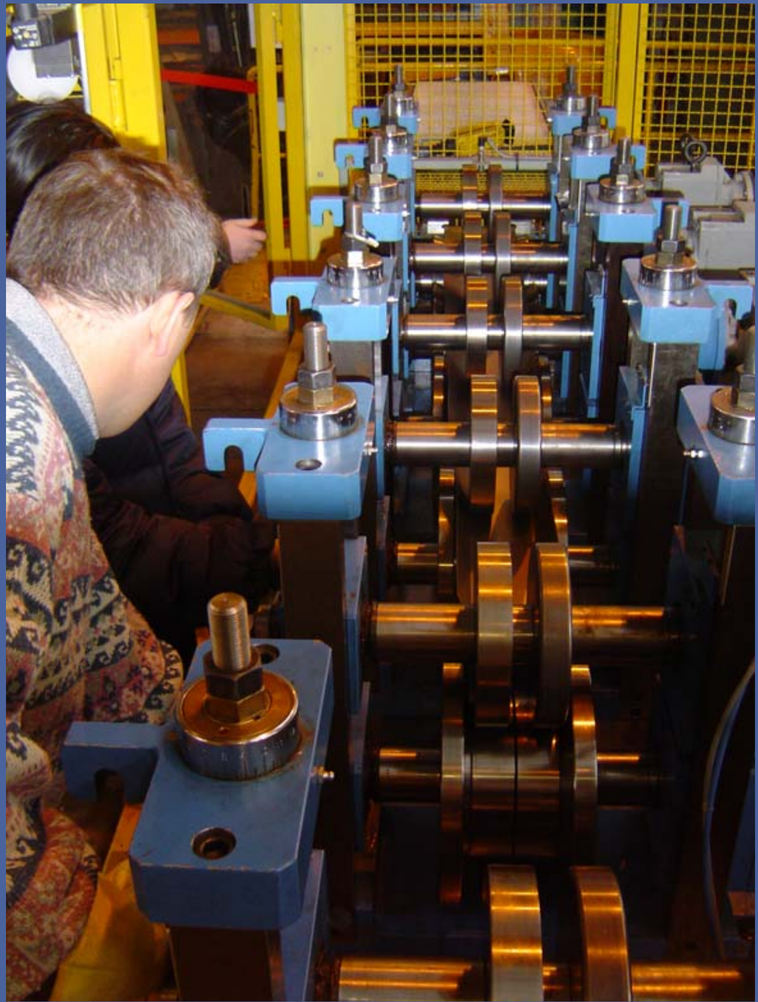


- Only the interesting part of the problem is meshed, thanks to the ALE formalism.
- The mesh is Eulerian in the rolling direction and Lagrangian in the transverse direction.
- The stationary state is reached by first clamping the sheet between the rolls and secondly making them rotate around their axis.
- The rolls are rigid and the sheet is thick.
- The free surface of the sheet in the outlet zone is automatically computed using spline remeshing.
- Eulerian convection of the Gauss points values is performed using a 1st order Finite Volume algorithm.

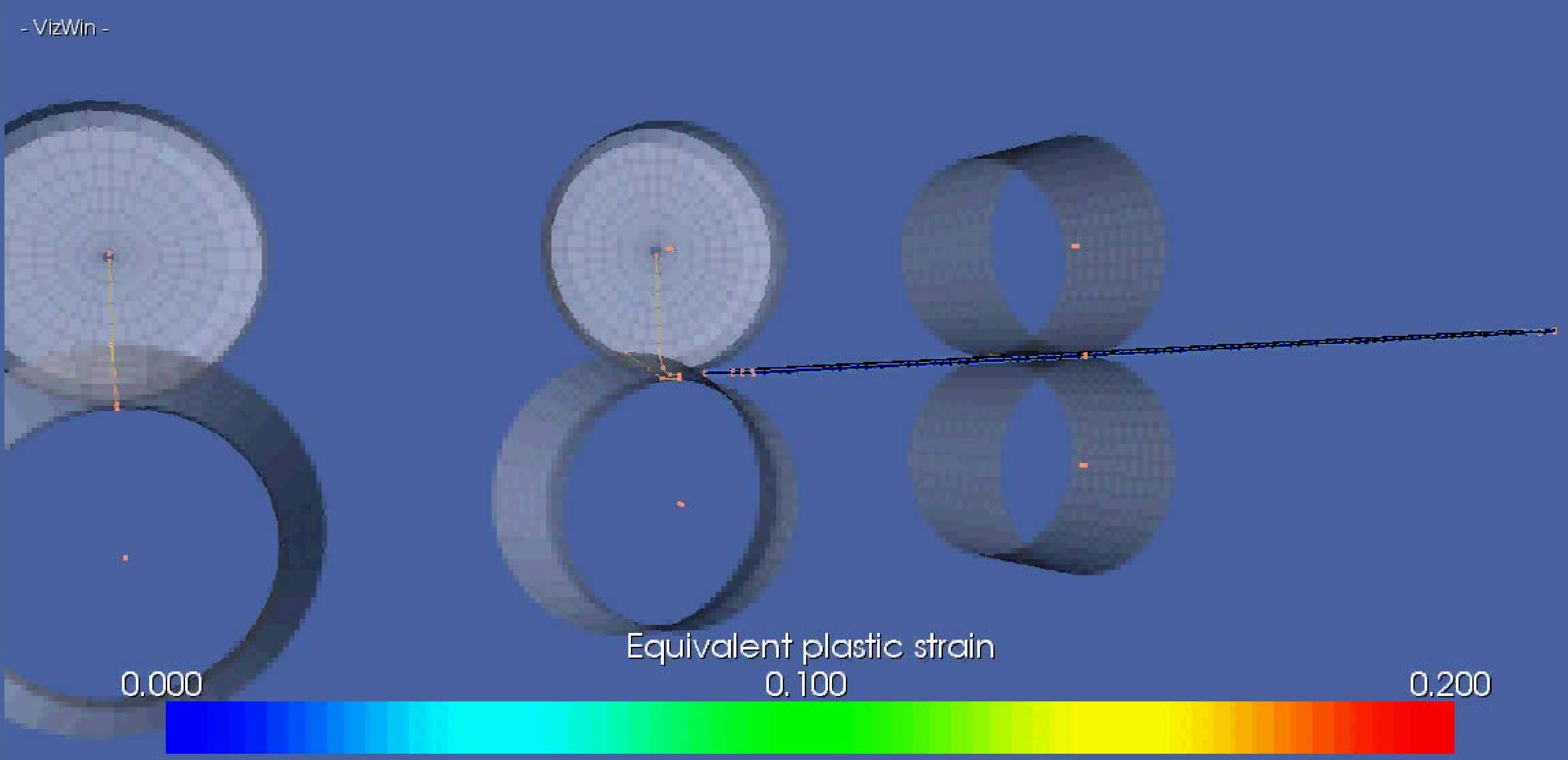
Roll forming



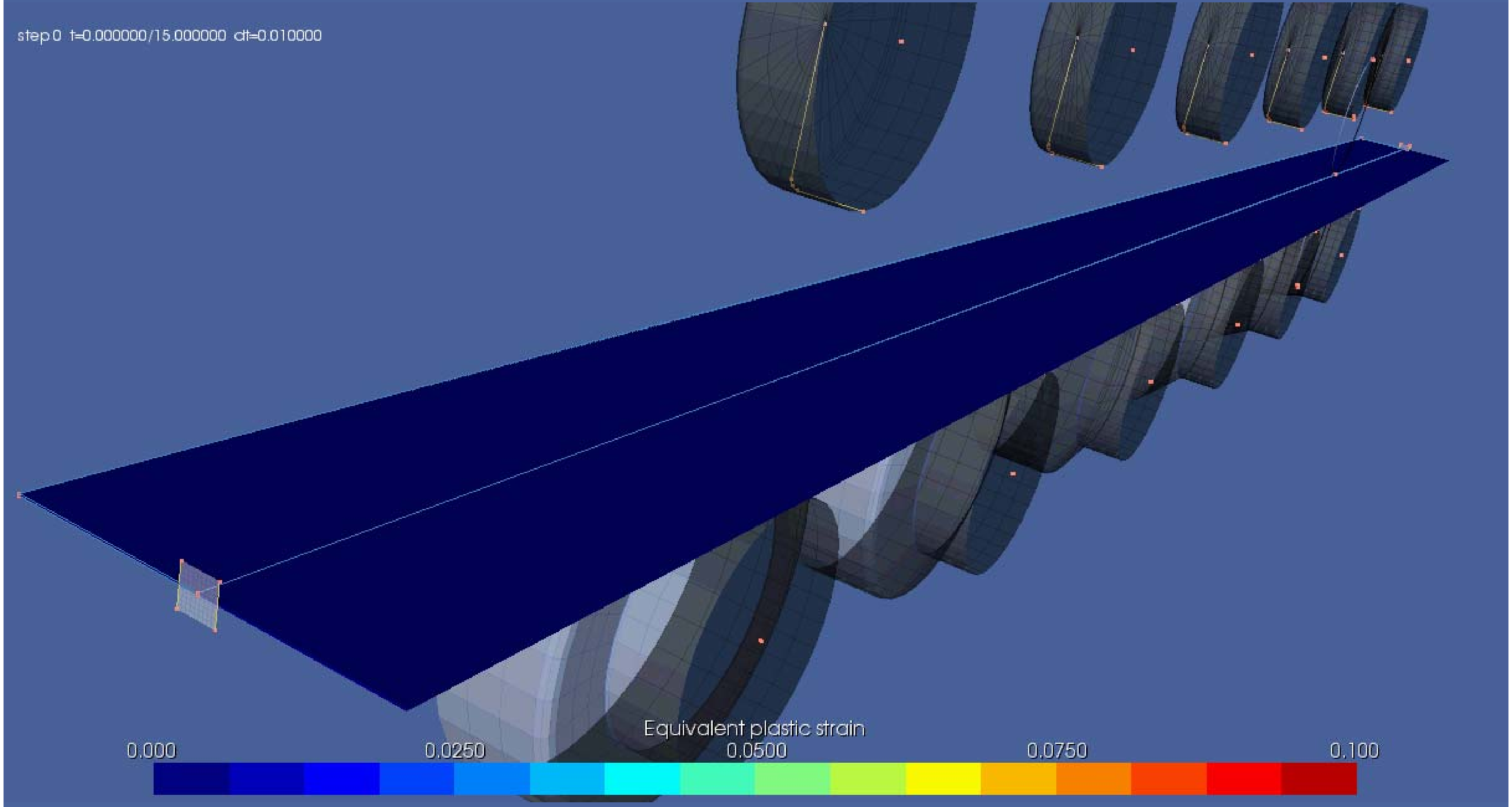




Roll forming – Lagrangian simulation



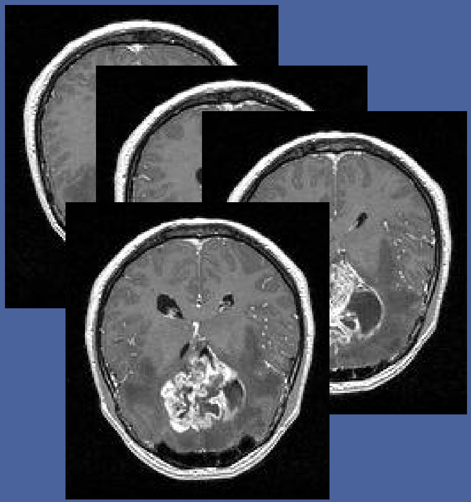
Roll forming – ALE simulation



Biomedical applications

1. Brain Model
2. Orthodontics

Brain Model

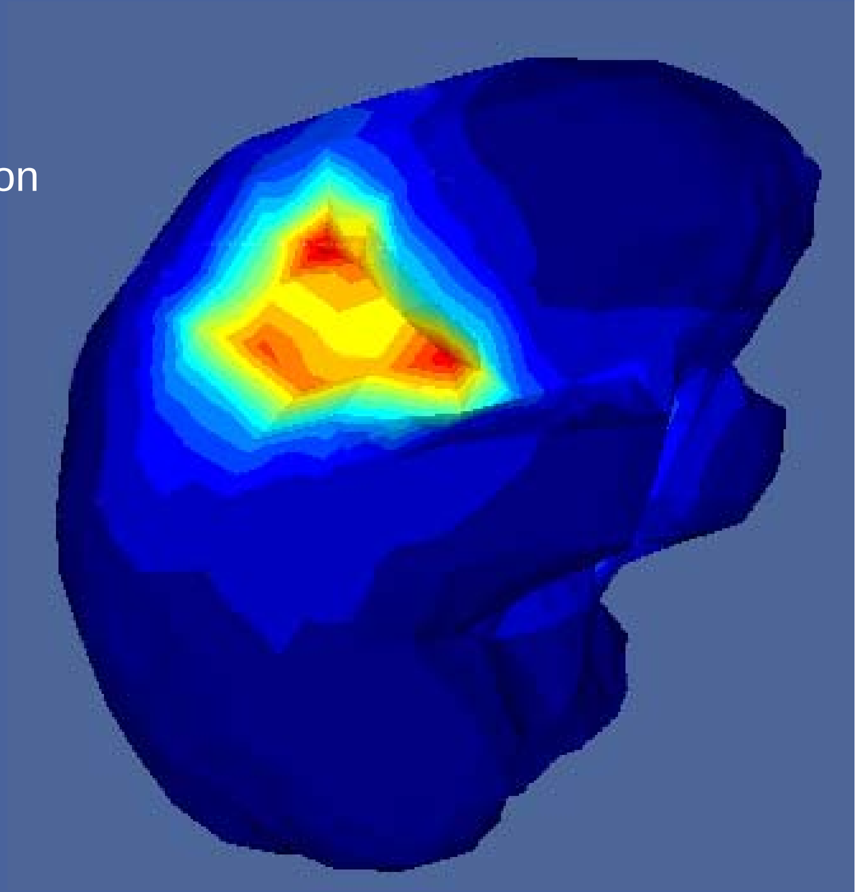


Segmentation

3D geometric reconstruction

Meshing

Loading conditions

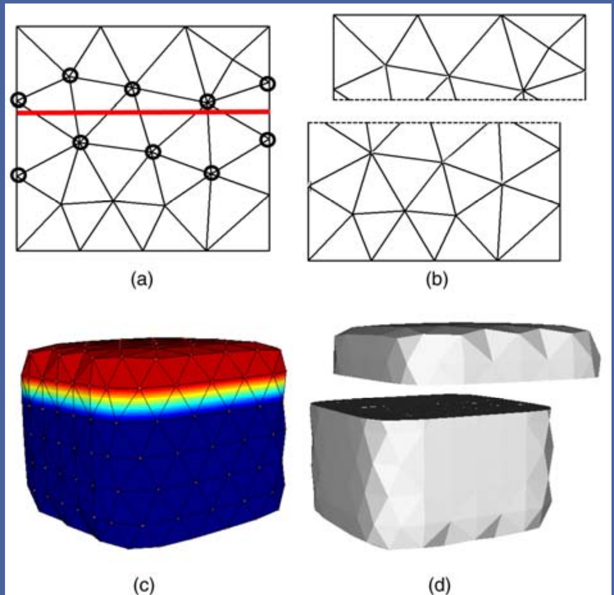


- Prediction of the deformations of a brain from intraoperative MR (Magnetic Resonance) scans during neurosurgery.
- Future simulations : brain shift due to gravity and CSF (Cerebrospinal fluid) leakage and draining, effect of tumor retraction and resection, etc.

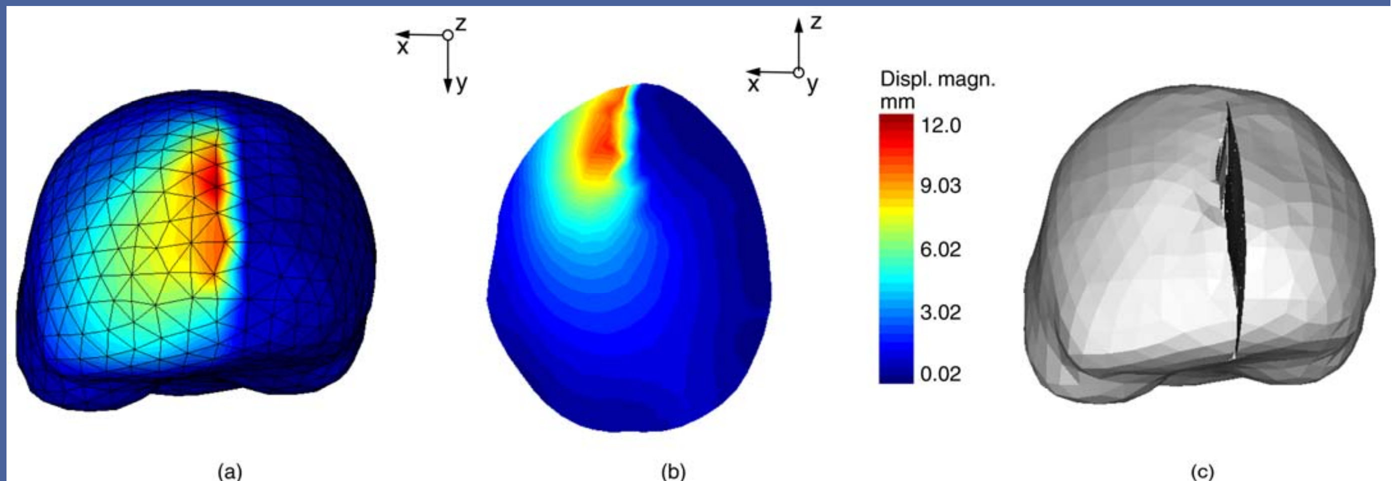
In collaboration with :

- Prof Verly (ULg) (medical imaging)
- Prof Cescotto (ULg) (material identification)
- Dr Robe (CHU-ULg) (neurosurgery)

XFEM Brain Model

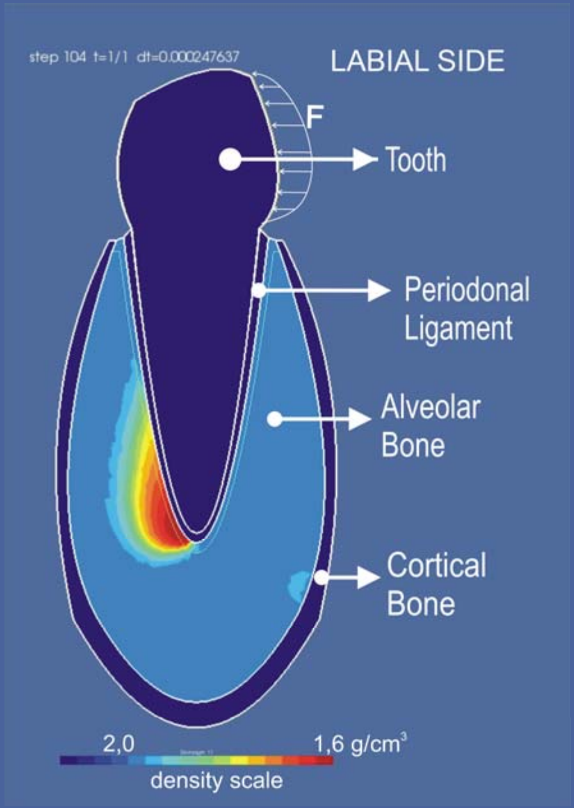


- Discontinuities in the displacement field (surgical cuts - retractions, resections) can be modelled using the 3D eXtended Finite Element Method (XFEM)
- In a near future, these simulations will lead to updated hi-res preoperative images that could help the surgeon using a neuronavigation system.

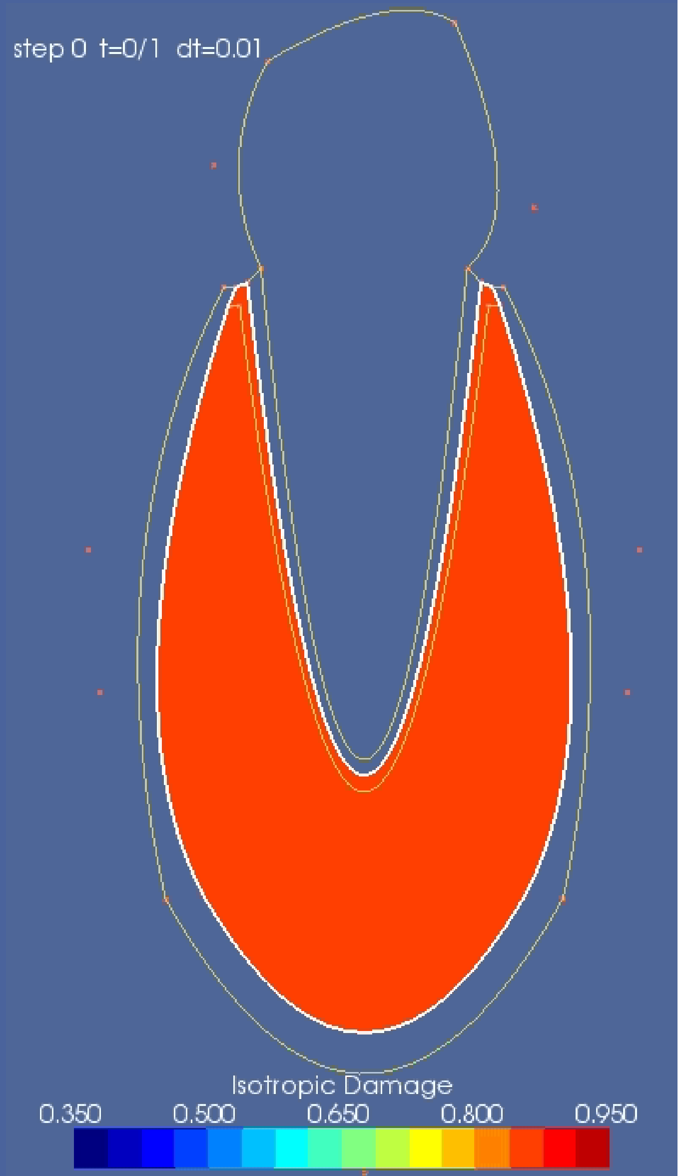


Tooth Model

- Orthodontics – alveolar bone remodelling
- Remodelling = bone density variation according to biomechanical stimulus.
- Case of alveolar bone surrounding teeth



- Use of damage as a measure of bone density
- Continuum damage model with specific damage variation law



The future

- Process chaining and optimization
- Material parameters identification
- Shells – higher order elements – enhanced triangles/tetrahedras
- More efficient contact-search algorithms (deep drawing of car panels)
- High performance computing (parallelization) : SMP then clusters
- Remeshing algorithms
- Improving the modularity and the efficiency of each library
- …