Recent developments in the Commercial Software LS-DYNA for electromagnetic pulse forming and joining simulations

Pierre L'Eplattenier
Iñaki Çaldichoury
LSTC

Outlook

LSTC Livermore Software Technology Corp.

- The electromagnetic (EM) solver in LS-DYNA
- Applications (3D solver)
  - Magnetic Pulse Forming
  - Magnetic Pulse Welding
  - Induction heating
  - Induction welding
  - Battery crash modeling
  - Contact: rail gun, short circuits
  - Magnetic flux compression
  - Resistive heating
  - Electromagnetic spot welding
  - Coil design and optimization
- 2D axisymmetric solver

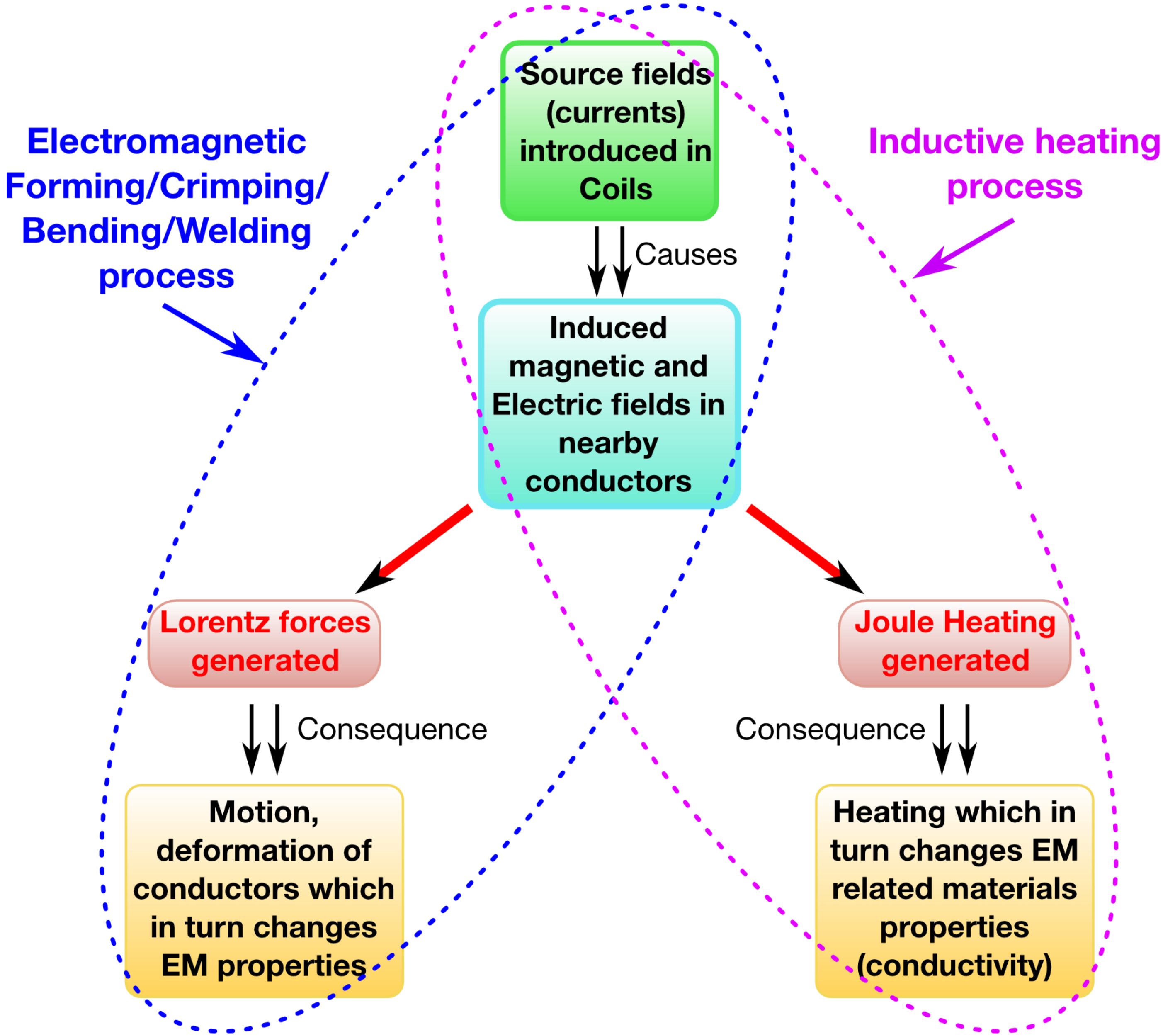
General presentation of LS-DYNA

LSTC
Livermore Software Technology Corp.

Finite element code for non linear transient dynamics

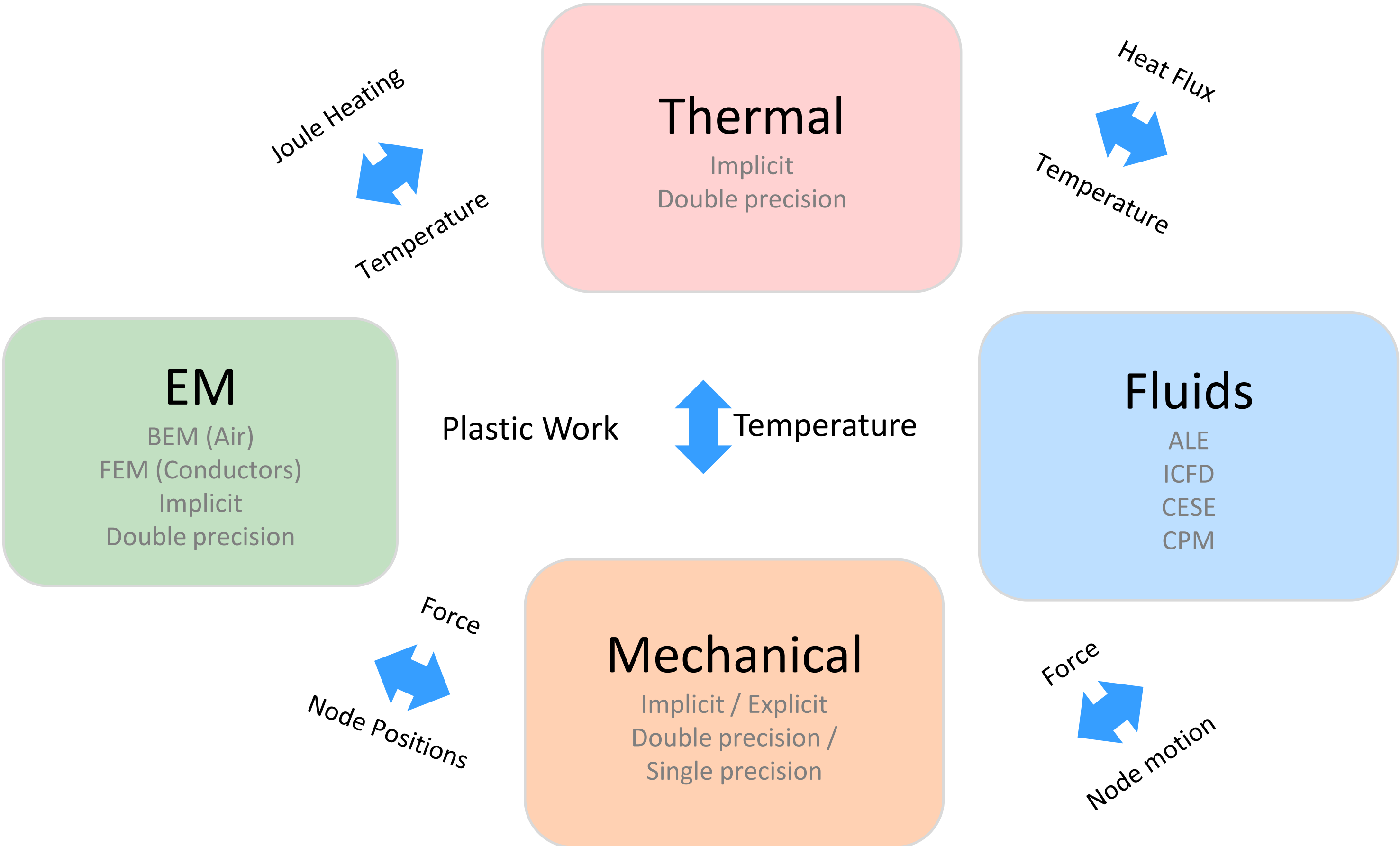
- 2-D and 3-D simulations with explicit/Implicit time integration
- Deformable & rigid bodies
- Numerous element types and formulations
- Around 150 constitutive (material) models
- 14 equations-of-state
- More than 35 contact algorithms
- Coupled thermal analysis
- Coupled fluid/structure analysis (Euler/ALE/Lagrange element formulations)
- Smooth Particle Hydrodynamics (SPH)
- … and … electromagnetics

EM 3D Solver


Electromagnetic Forming/Crimping/ Bending/Welding process
Source fields (currents) introduced in Coils
Causes
Inductive heating process
Induced magnetic and Electric fields in nearby conductors
Lorentz forces generated
Joule Heating generated
Consequence
Consequence
Motion, deformation of conductors which in turn changes EM properties
Heating which in turn changes EM related materials properties (conductivity)

LS-DYNA coupled simulations

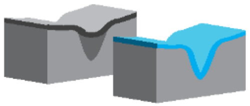
LSTC
Livermore Software Technology Corp.



EM 3D Solver

- FEM (conductors) coupled with BEM (surrounding air)
- Automatically coupled with Mechanical and Thermal
- Possible to couple it with fluid solver
- Available in MPP
- EM contact capability
- EM fields can be visualized in LS-PREPOST (same environment as Mechanical, Thermal, …)

Magnetic Pulse Forming (MPF)

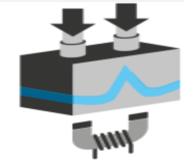


Achieve higher formability than traditional methods

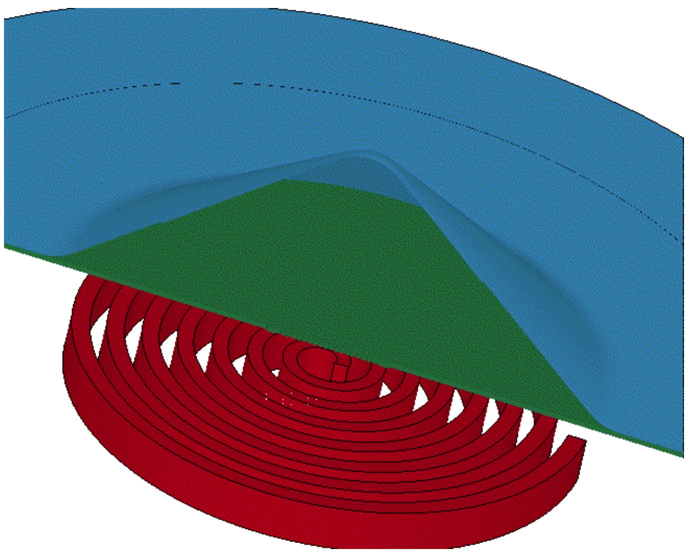
Can produce Sharp corners and fine details

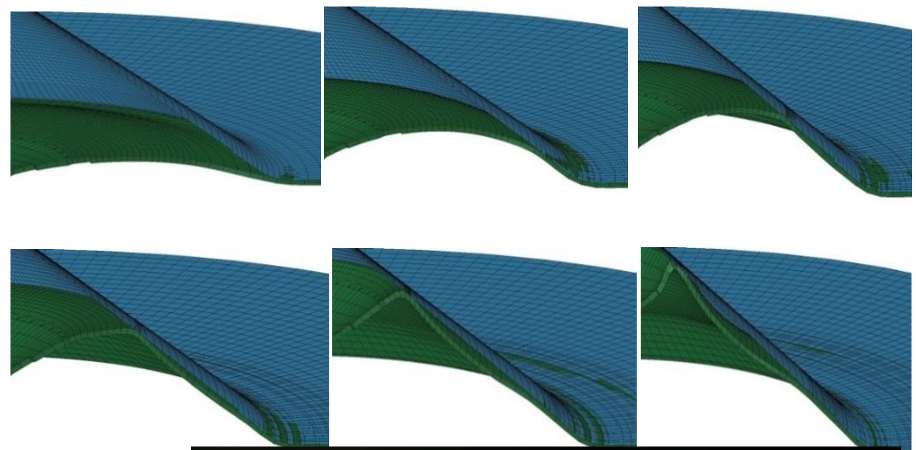
Greatly reduced springback and good stress distribution

Use one sided die (Optional - none metallic die)



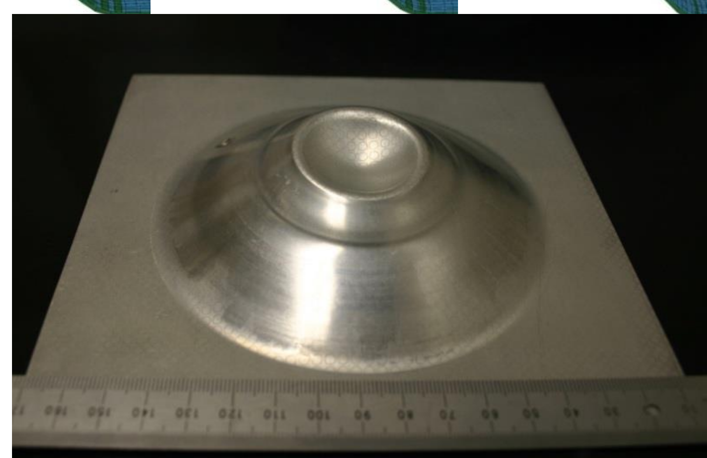
Can be combined with any other forming technology





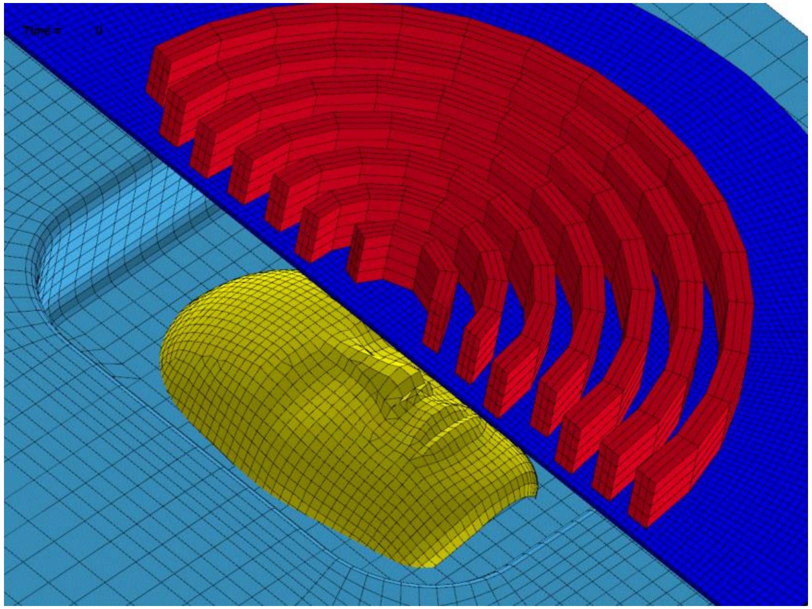
Sheet forming on conical die

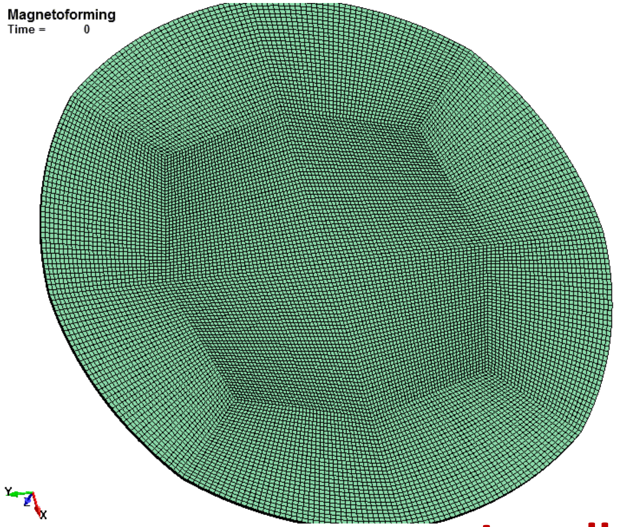
UNIVERSITY OF WATERLOO



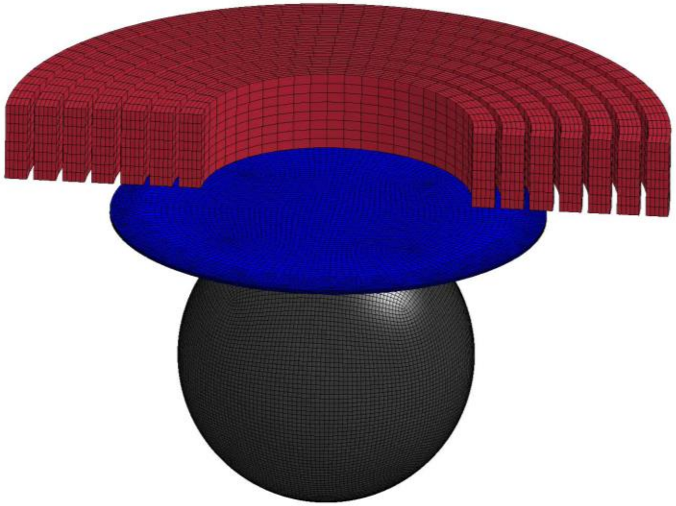
In collaboration with:
M. Worswick and J. Imbert
University of Waterloo, Ontario, Canada

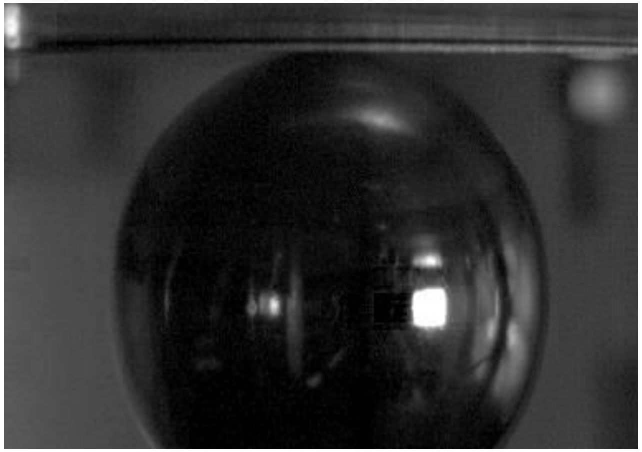
Magnetic Pulse Forming (2)





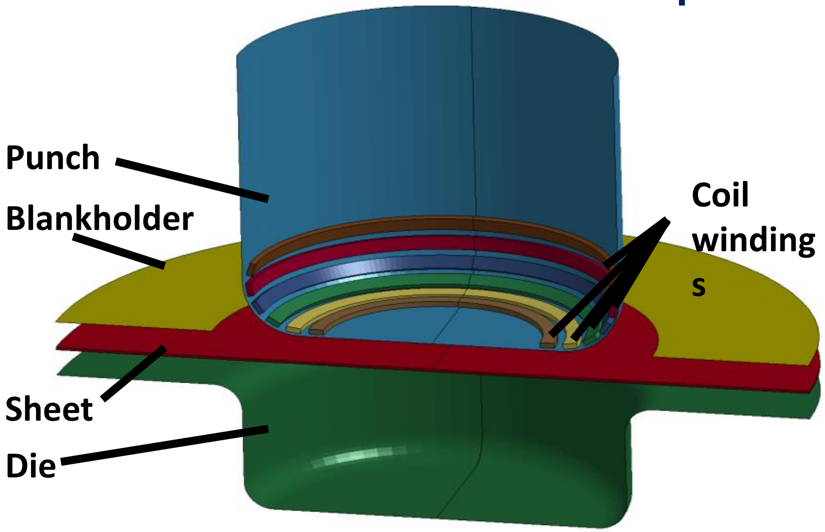
In collaboration with
G. Mazars, G. Avrillaud,
Bmax, France

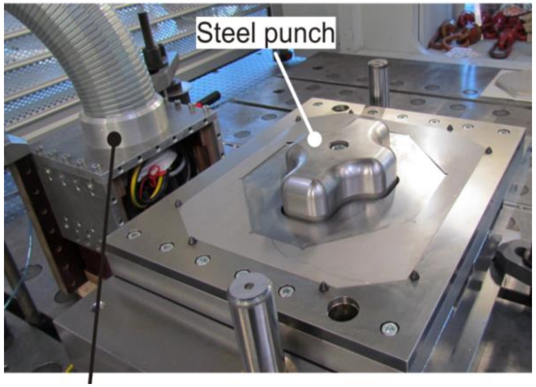


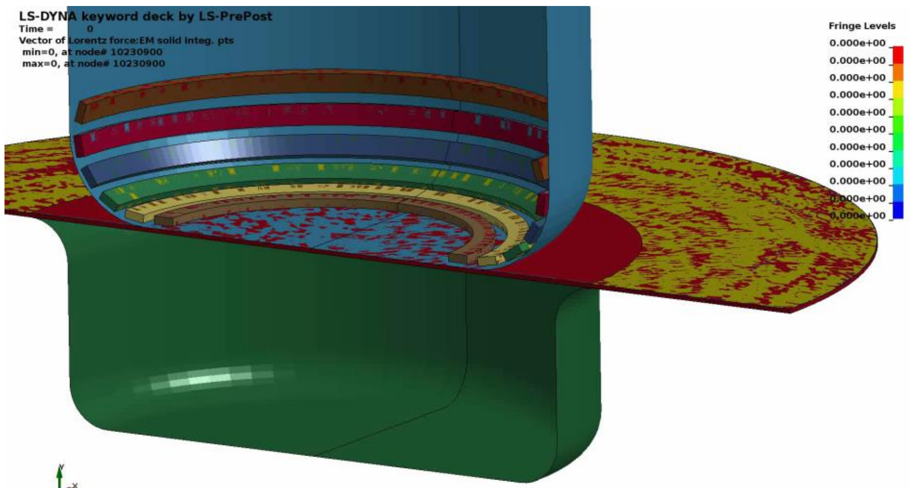


Magnetic Pulse Forming (3)

Combined deep drawing + MMF







Courtesy of Y. Kiliclar, IUL, TU Dortmund

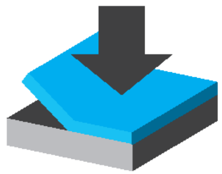
Magnetic Pulse Welding (MPW)

LSTC Livermore Software Technology Corp.

MPW is a solid state cold welding

generated by high speed collision between two metals at room temperature

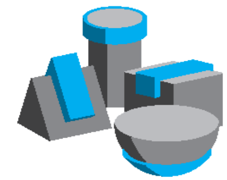
millisecond



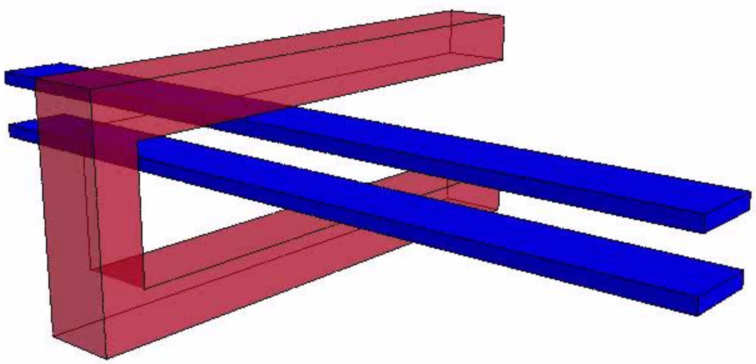
Dissimilar

No heat affected one

High performance joining,thinner parts



Different shapes



Simulations are used to determine the collision parameters (3D) to insure a good weld:

- **Impact velocity**
- **Impact angle**

Bmax

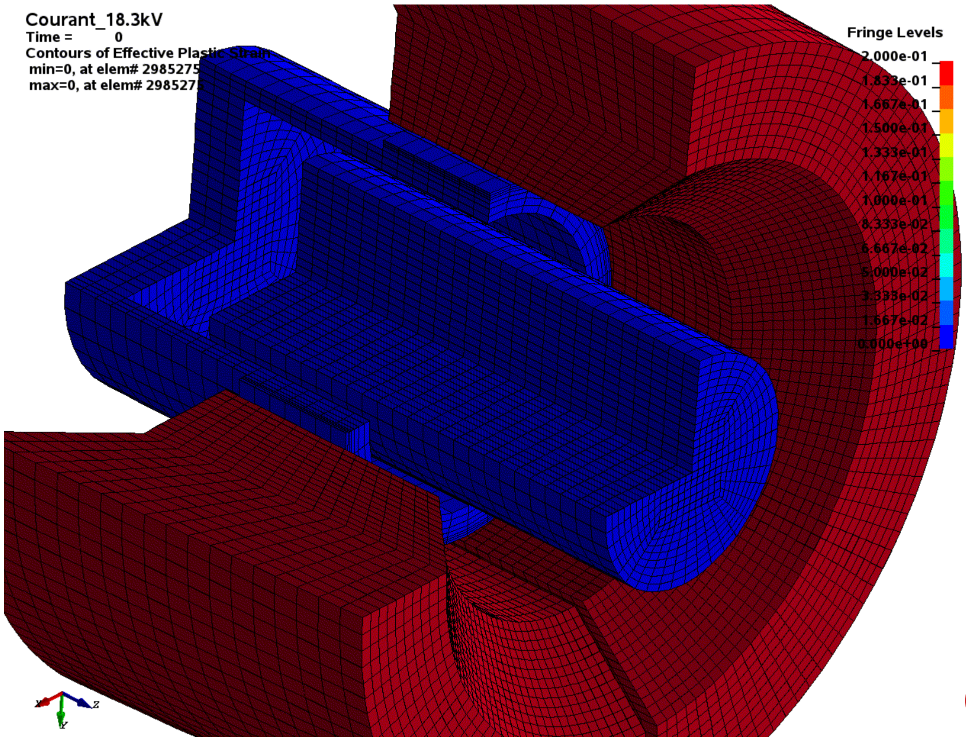
THE OHIO STATE UNIVERSITY

UNIVERSITY OF WATERLOO

MONDRAGON UNIBERTSITATEA

Magnetic Pulse Welding

Weld of an outer tube onto an inner one



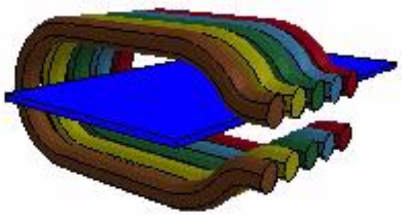
Courtesy of G. Mazars, Bmax, France

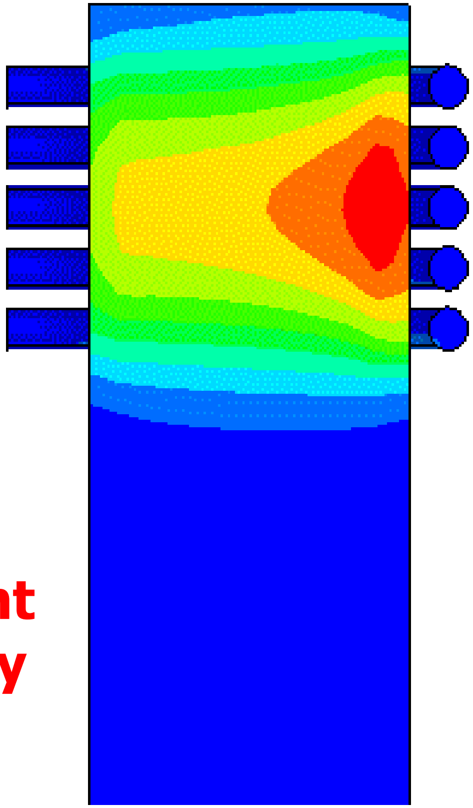
Bmax

Induction heating

Current induced by a coil -> Joule heating

Temperature



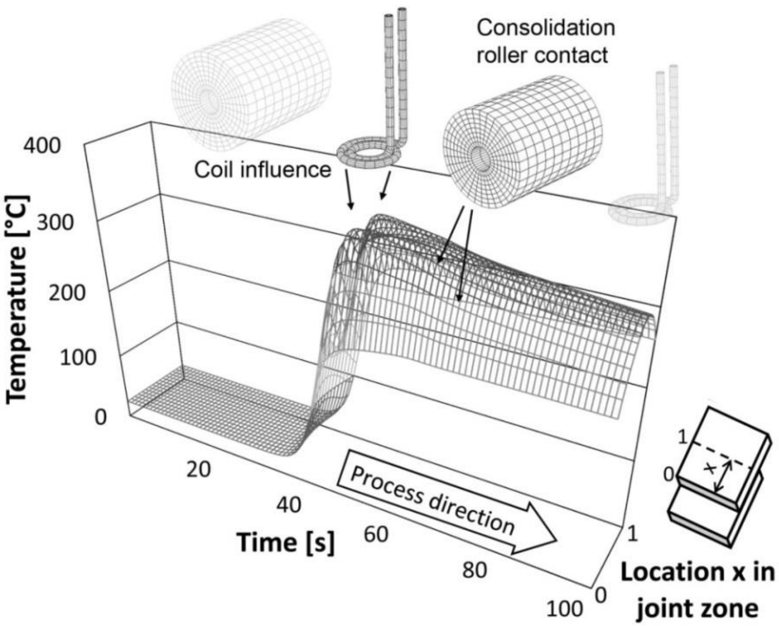


Current density

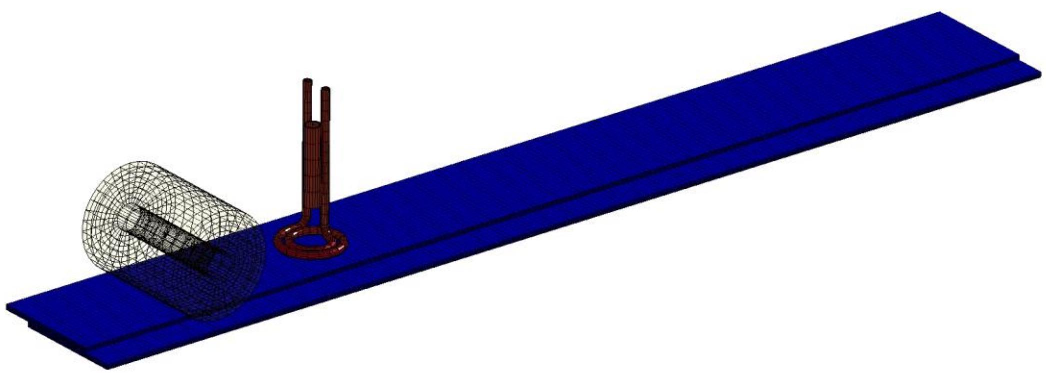
- Conducting plaque moving though Coils,
- Coils generate Joule heating in the plaque,
- Induced heating problem coupled with the Thermal solver of LS-DYNA.

Continuous induction welding

Induction heating
Mechanical pressure applied for consolidation and maintained during cooling.



BMW M-series composite front bumper (source: Jacob Composite GmbH)

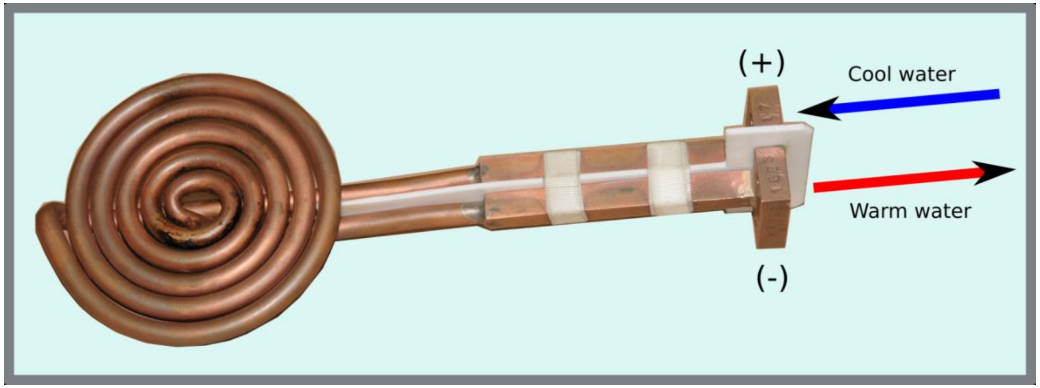


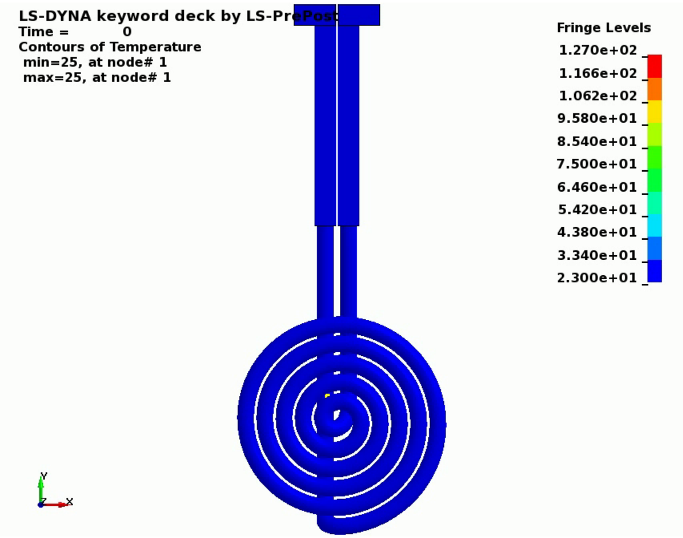
In collaboration with:
M. Duhovic,
Institut für Verbundwerkstoffe, Kaiserslautern, Germany

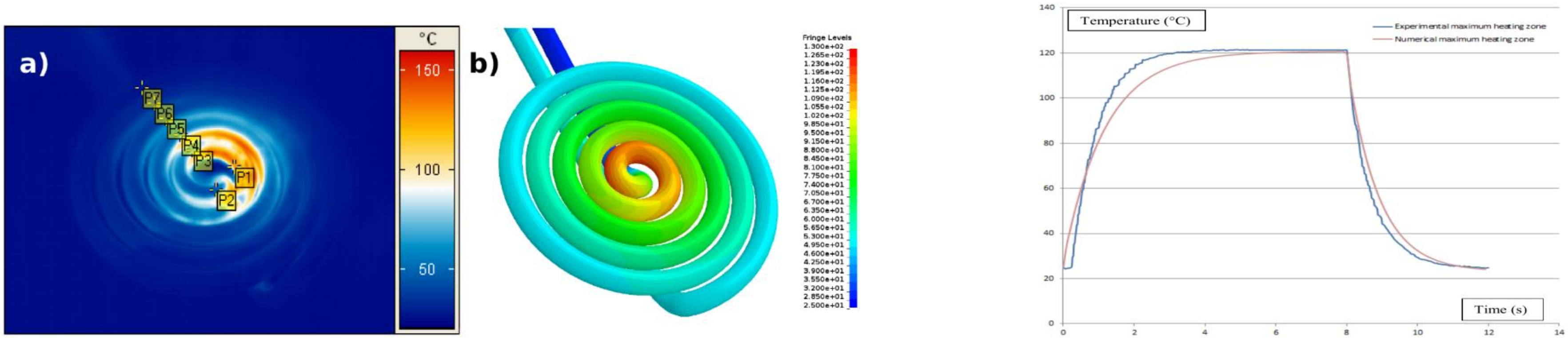
Institut für Verbundwerkstoffe

Cooling of a coil by a flow of fluid (ICFD + thermal + EM)

The electric current heats up the coil so water is injected and circulated to avoid melting of the coil



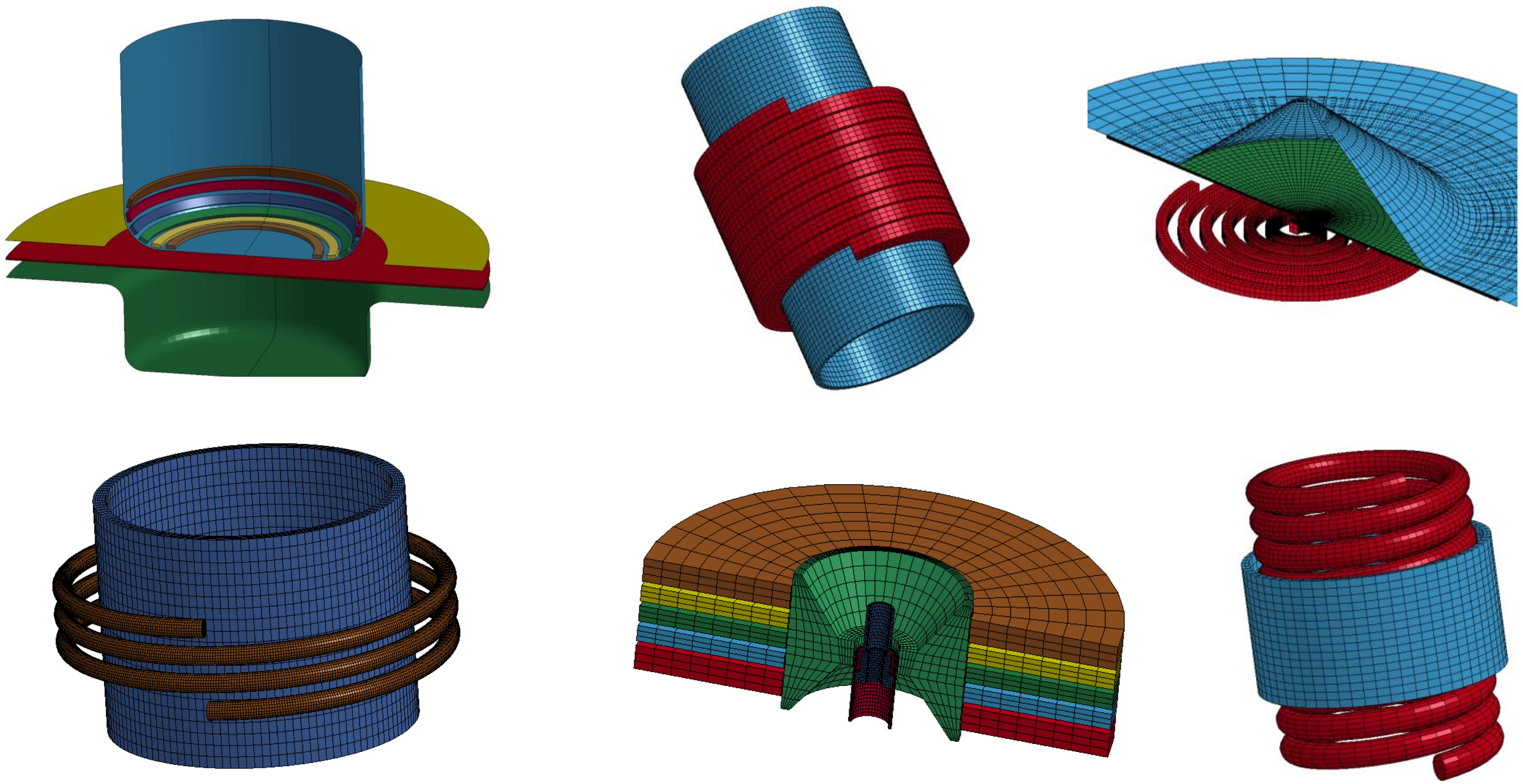




Experimental/numerical comparisons

In collaboration with: M. Duhovic, Institut für Verbundwerkstoffe, Kaiserslautern, Germany

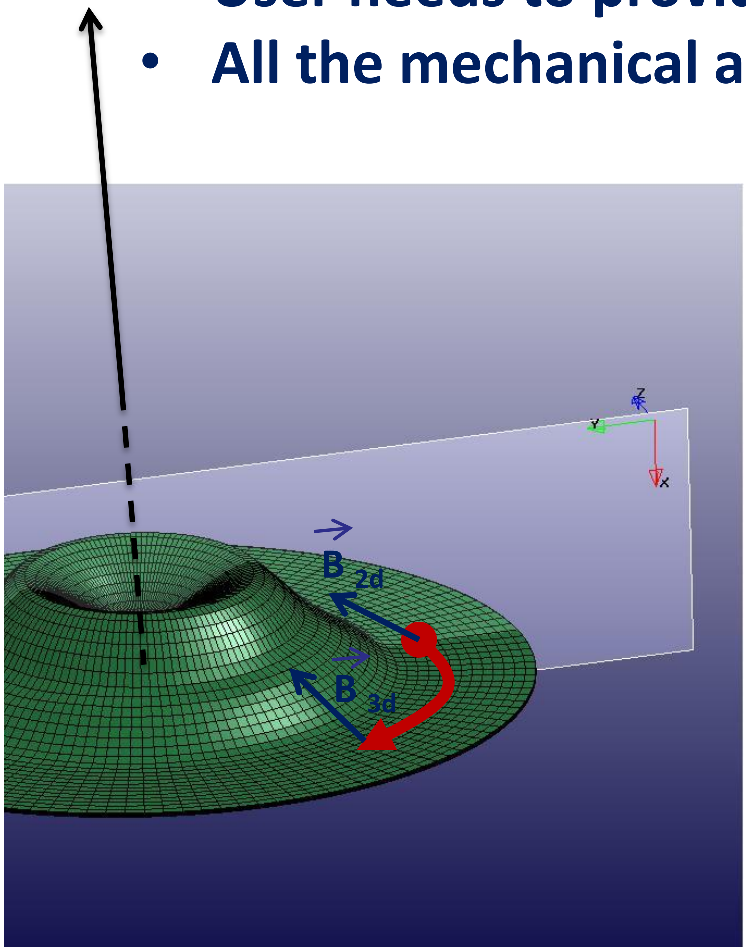
Many EM models are (quasi) axisymmetric



- Many geometries have (or nearly have) a cylindrical invariance (coils, field shapers,…)
- The pitch of a coil is generally small to limit the inductance
- => Introduction of EM 2D axisymmetric solver

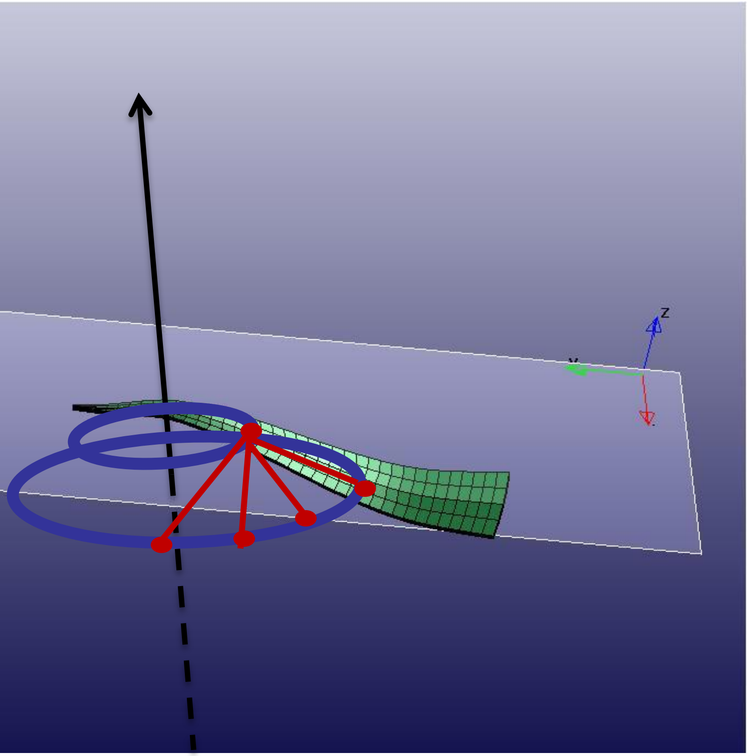
EM 2D : basics

- **EM 2D coupled with mechanics and thermal 3D**
- **User needs to provide a 3D mesh with rotational invariance**
- **All the mechanical and thermal 3D capabilities available**



- EM solved in a plane
- EM fields from 2D to 3D by rotation around the axis
- This process includes EM force and Joule Heating
- EM properties in the plane (σ, …) = average over 360 º

EM 2D : numerical method



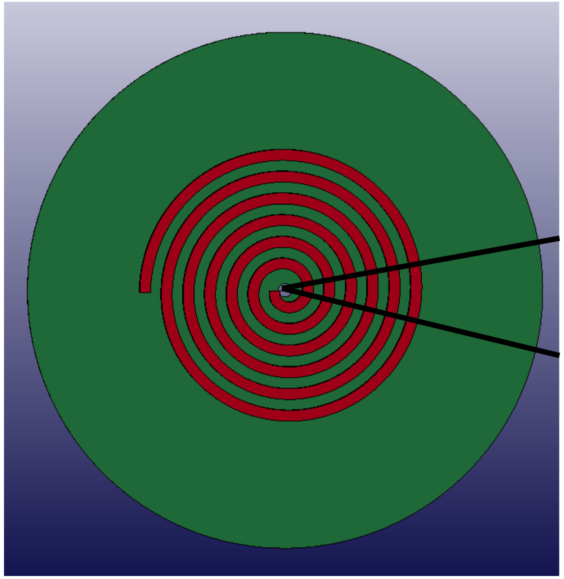
- EM solved by combined FEM + BEM (as in 3D)
- In the BEM, change in the kernel to take into account integration over full circle.
- The simulation can be done on a slice of the full 360 º , with suitable mechanical and thermal boundary conditions

Capabilities

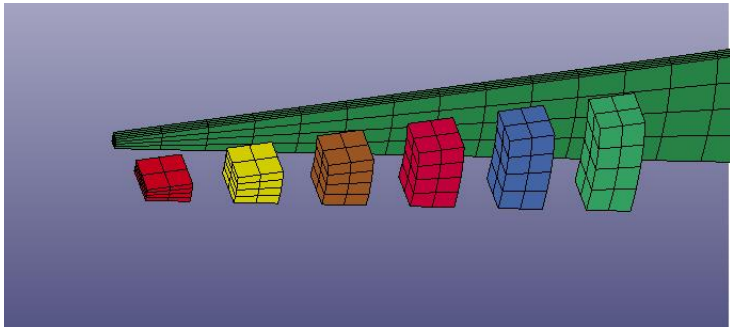
LSTC Livermore Software Technology Corp.

- Coupled with 3D mechanics and thermal, hence all the 3D features of LS-DYNA are available
- Allows coupling with all circuits (including RLC).
- Allows connecting different circuits together (e.g. for helix, spiral)
- EM contact available
- Available in MPP

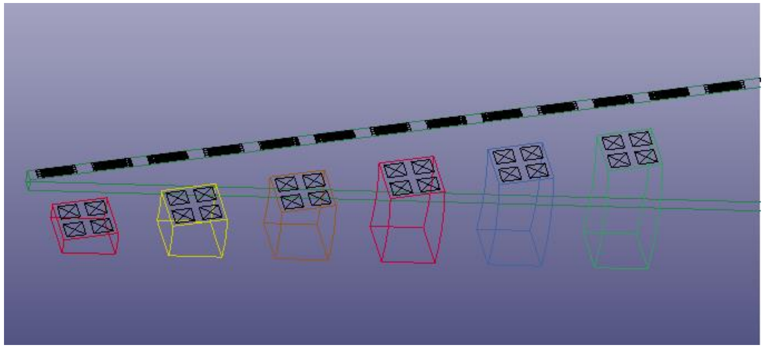
How to set up a 2D axi case



Slice of the full 360 ° mesh

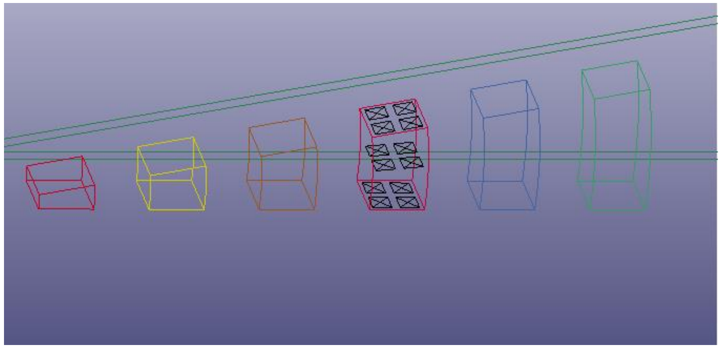


Define mechanical/thermal boundary conditions (e.g.) *BOUNDARY_SPC_SET



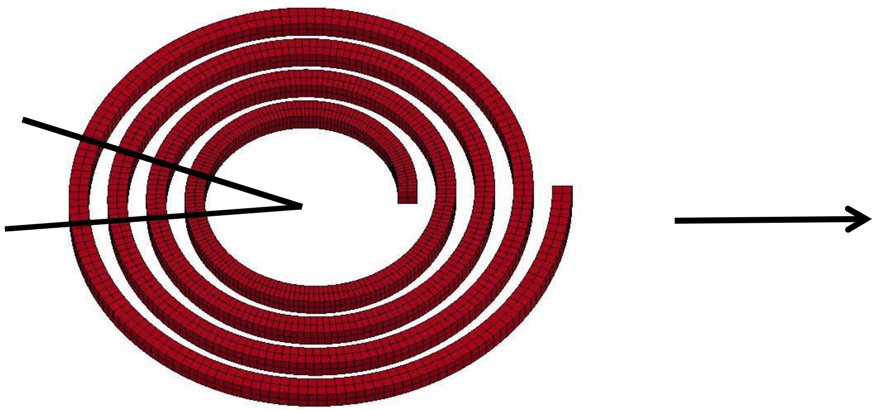
Define EM 2D:

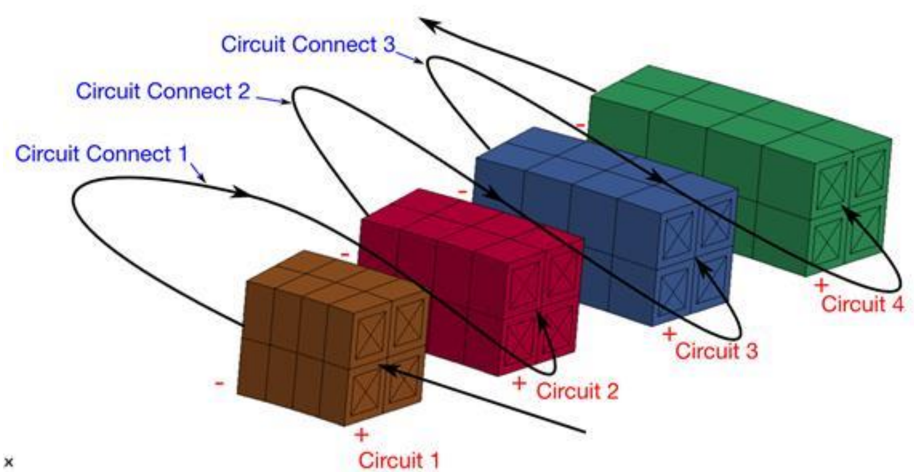
- 2D plane
- SSID in
- SSID out



Circuit connection

- 2D axi can be connected to any kind of circuit
- Circuits can be connected
- It is hence possible to model a helix/spiral coil, even connected to a RLC circuit





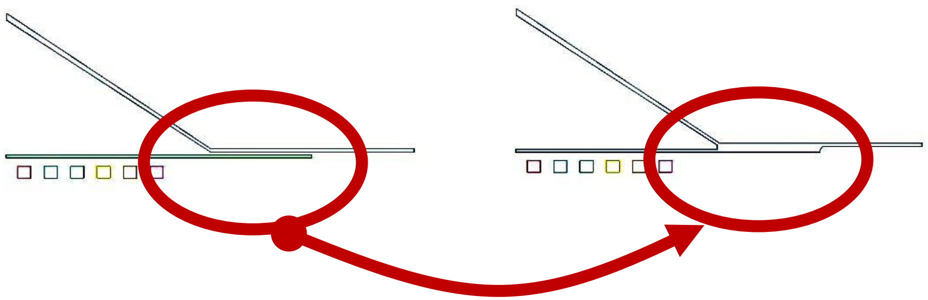
*EM_CIRCUIT_CONNECT

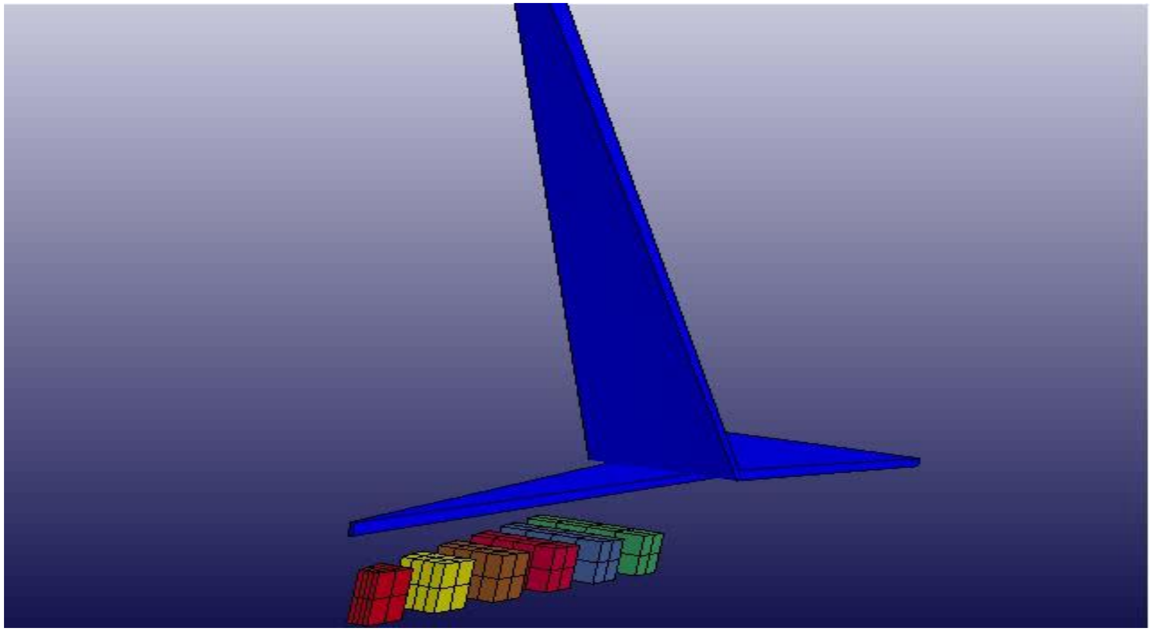
CONNID	CONNTYPE	CIRCID1	CIRCID2	C1	C2		
1	1	1	2	1	-1		

Imposes: $c_1 * i_1 + C_2 * i_2 = 0$

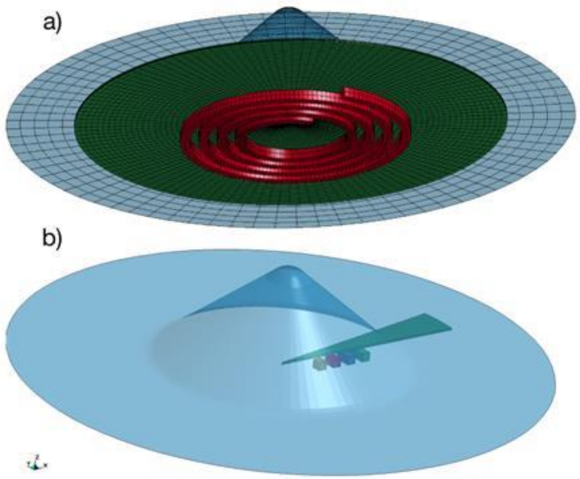
Contact

- The 2D contact works the same way as the 3D one:
  - Constraints on the FEM system
  - Local re-meshing if the BEM mesh

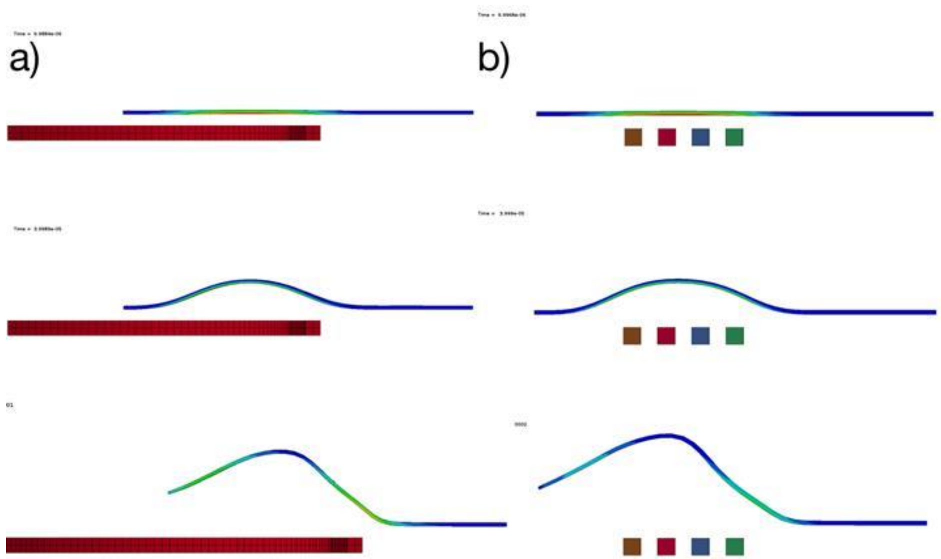




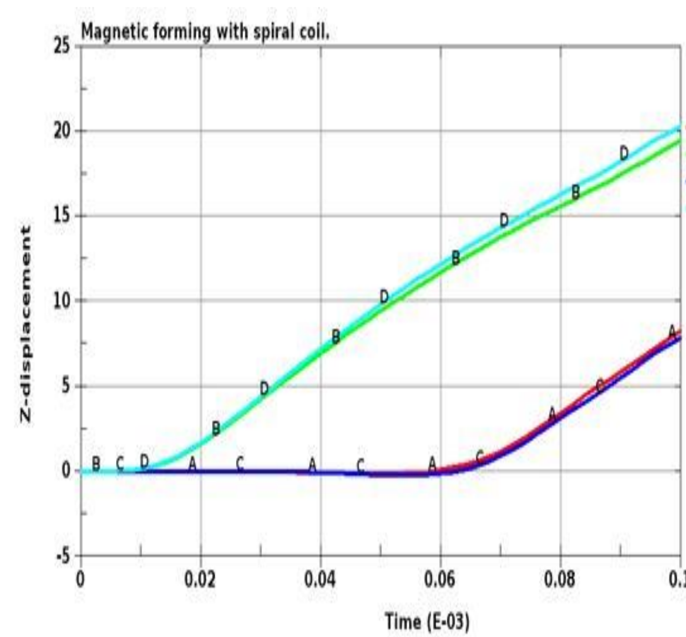
Comparison 3D – 2D axi (2)



- Forming of a plate with a spiral coil
- Coil connected to RLC circuit

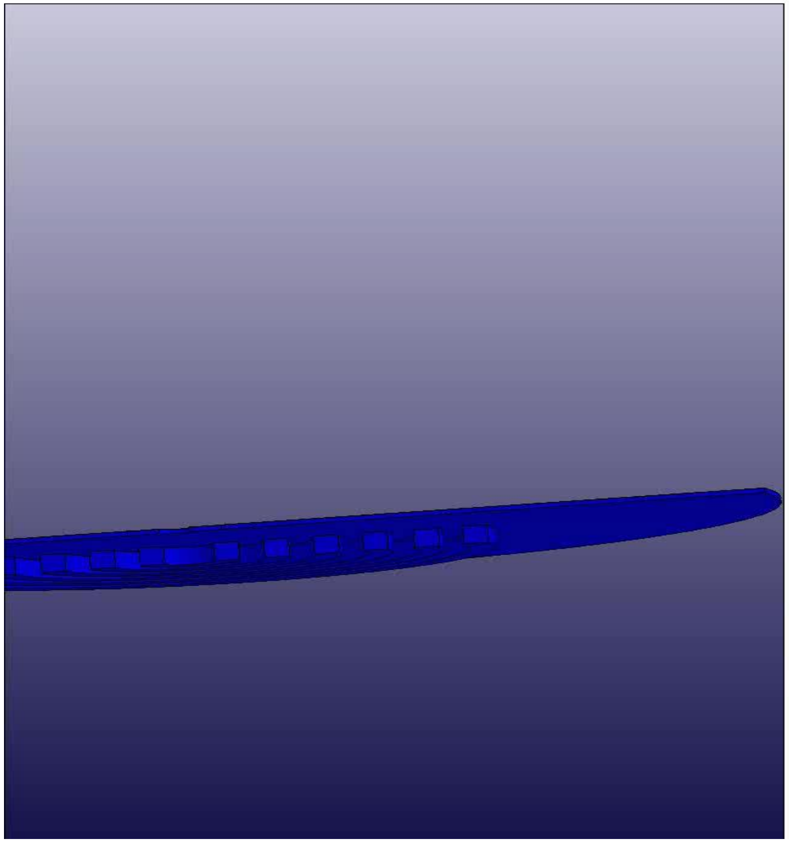


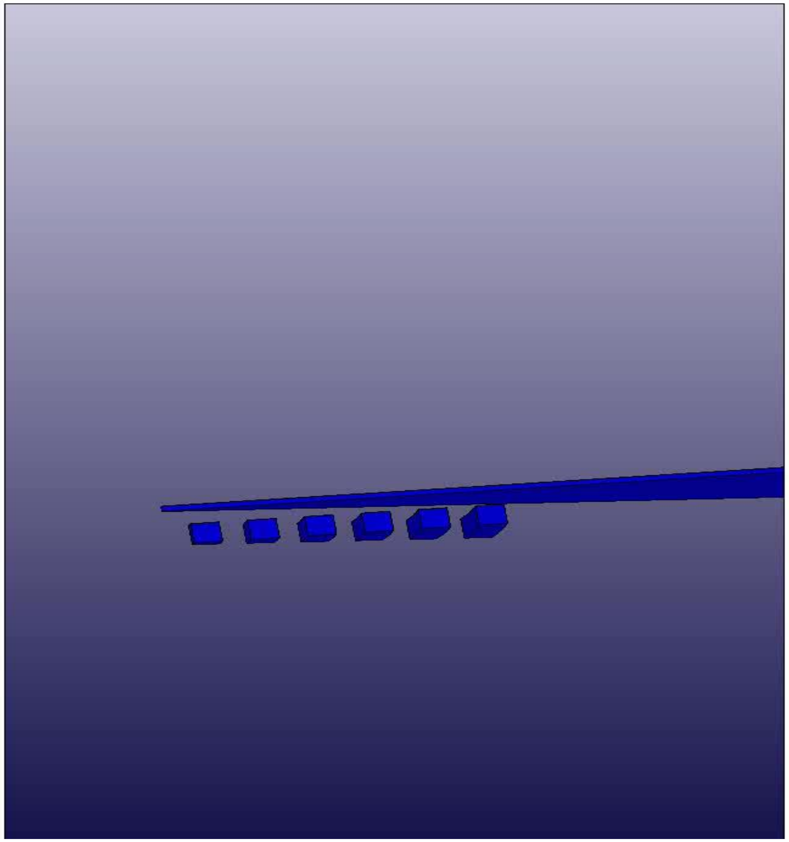
3D 2D



3D vs 2D – z vs time at 2 nodes

Comparison 3D – 2D axi (3)



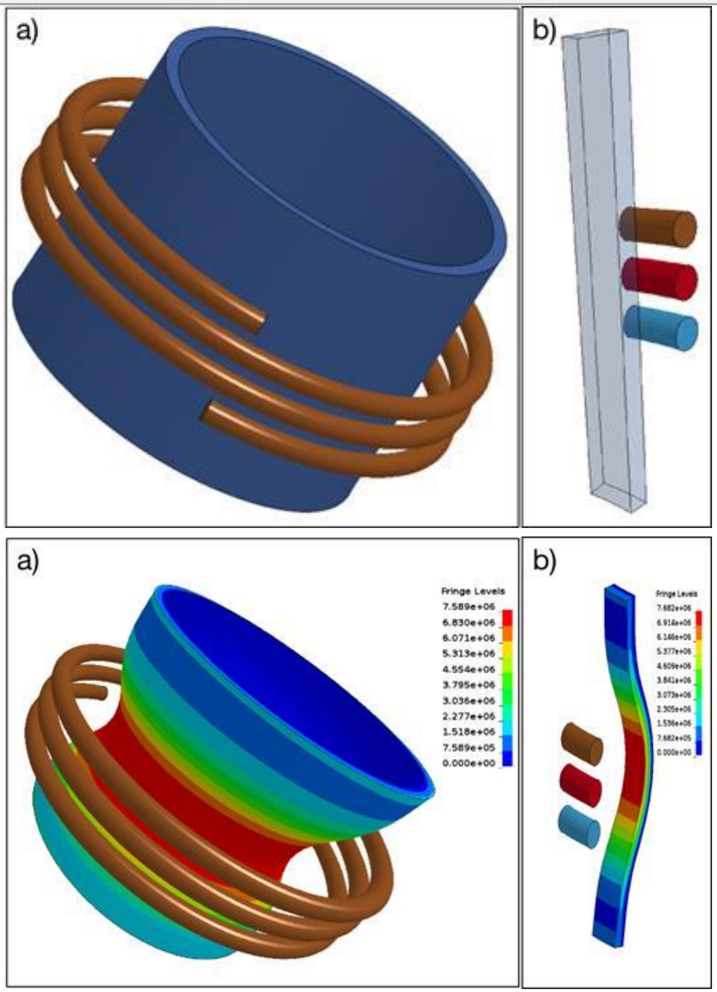


3D : 30 mn on 12 CPU

2D : 5 mn on 1 CPU

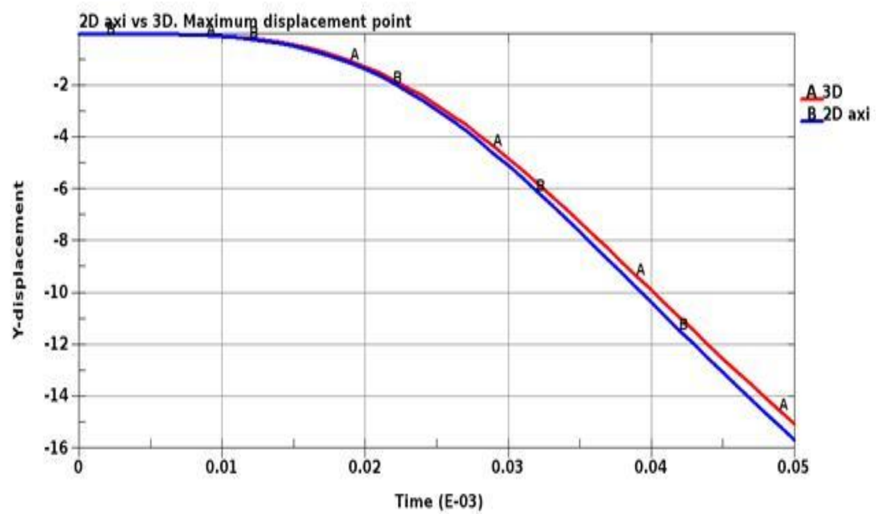
Comparison 3D – 2D axi (1)

LSTC Livermore Software Technology Corp.



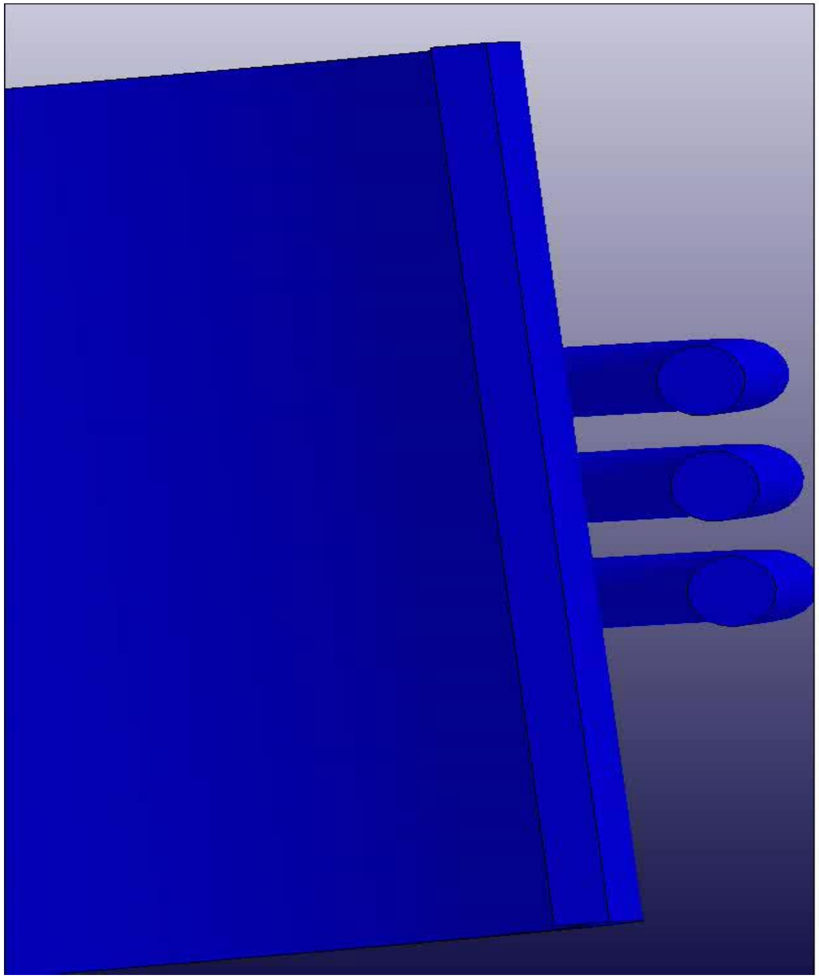
3D 2D

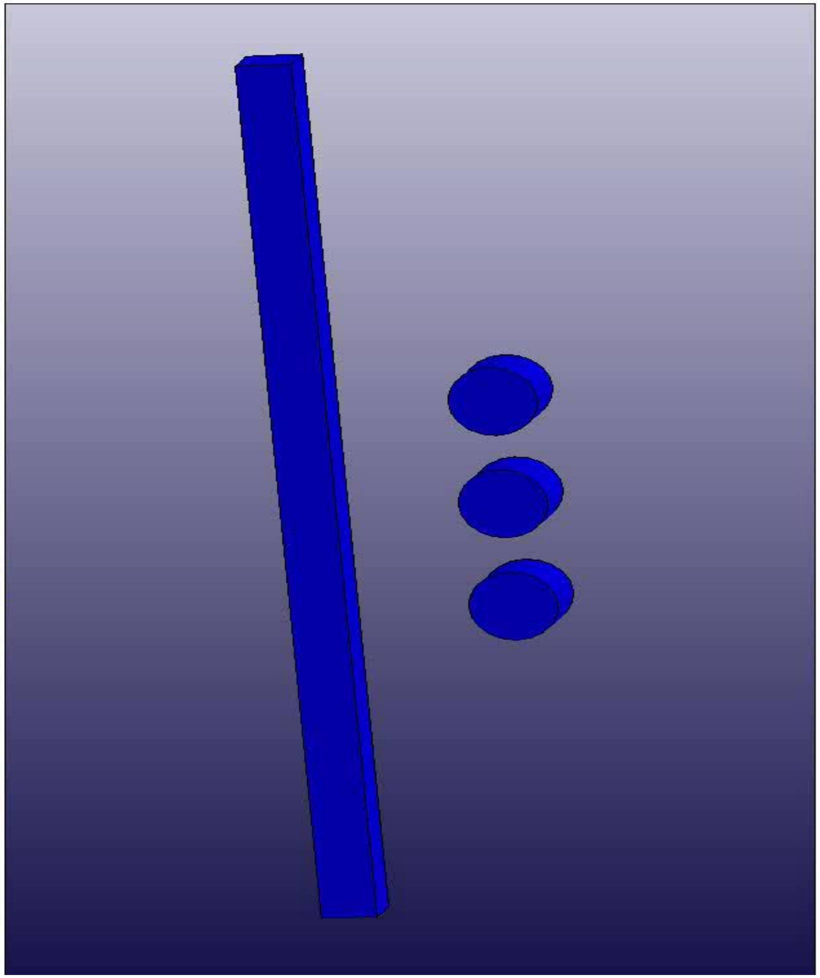
- Forming of a tube with a helix coil



3D vs 2D – central radius vs time

Comparison 3D – 2D axi (1)

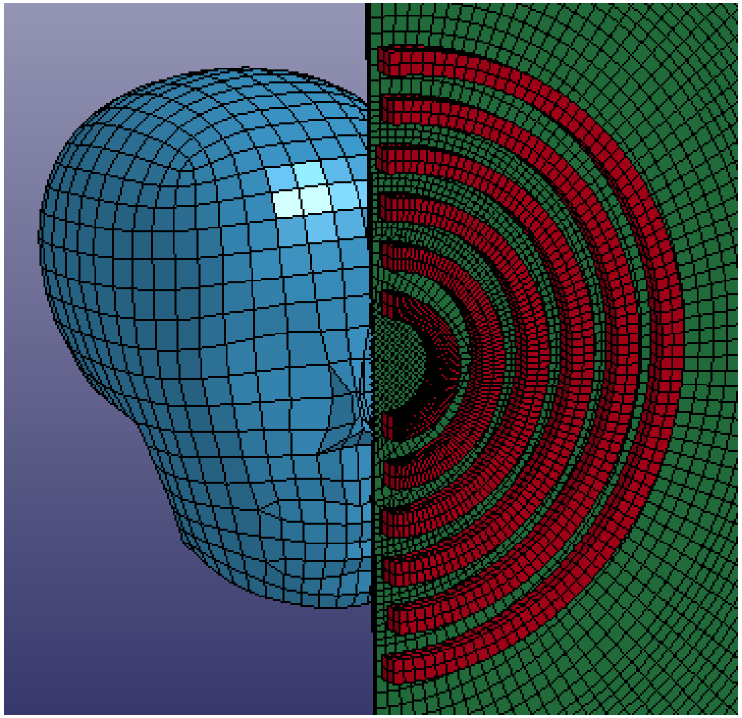




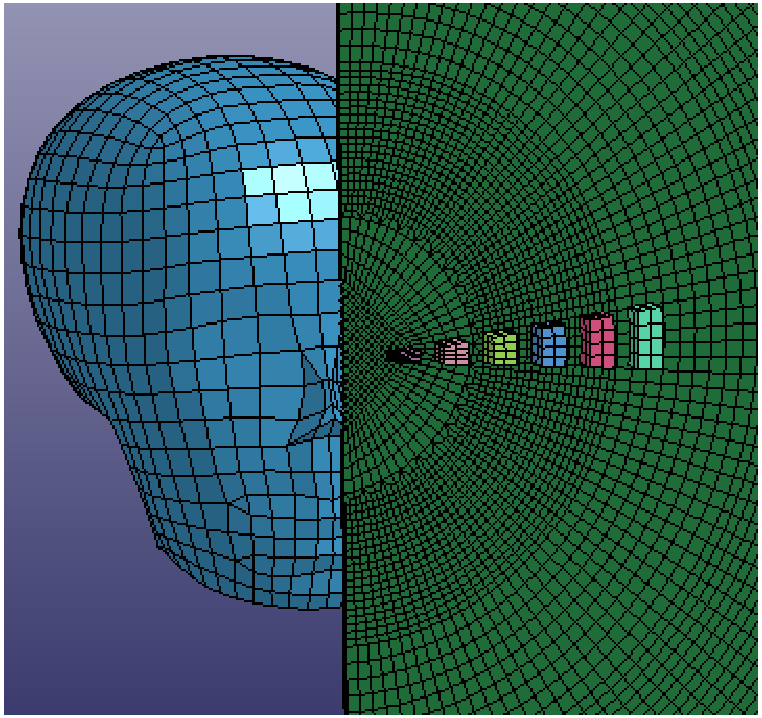
3D : 2 hours on 24 CPU

2D : 5 mn on 1 CPU

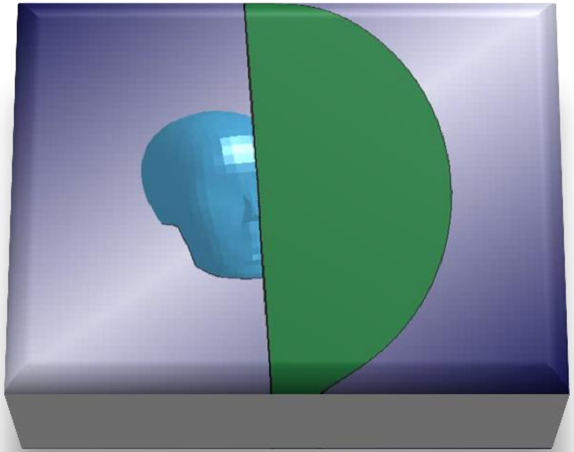
Plans: coupling EM-3D and EM-2D



All in 3D



- Coil in 2D
- Plate in 3D
- Die in 3D



Plans for the Future

- **Add 2D + 3D coupling**
- **Add erosion (element deletion) to EM**
- **Add magnetic materials**
- **Add piezoelectric materials**

Thank You