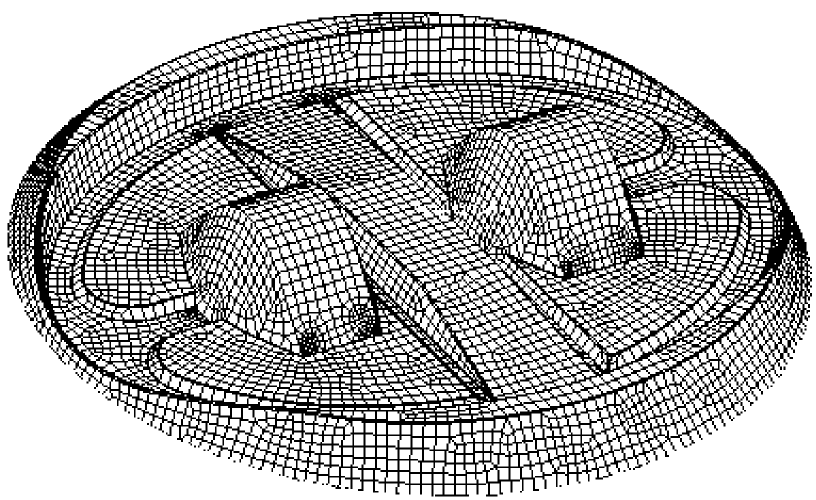
Presented at the COMSOL Conference 2009 Milan

Multiphysics Modelling in the Steel Industry



Filip Van den Abeele and Patrick Goes

OCAS and ArcelorMittal R&D

- Joint venture between steel supplier ArcelorMittal and the Flemish government
- Innovation and expertise centre for metal oriented research and development

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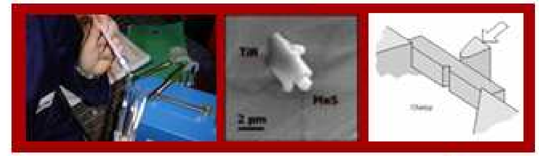
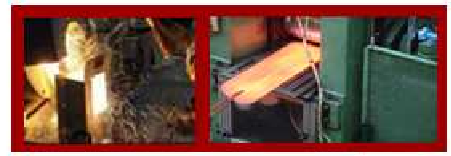
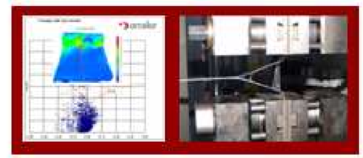
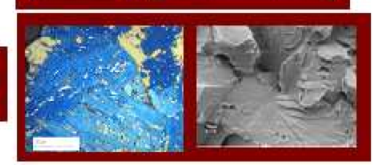
OCAS, an R&D service provider

- Training

- Material characterization

- Metallurgical processing

- Problem solving

- Fast prototyping & pre-production

- Co-design & Co-engineering

- Research & Development partnership


Steel Solutions and Design

New alloys and coatings

steel grades for energy transport

steel grade development for plates

improved efficiency electrical steel

steel grades for the future hydrogen economy

lab scale hot rolling

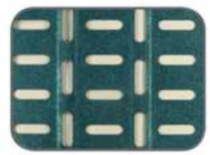
weight reduction thanks to ultra high strength steel

Surface functionalisation

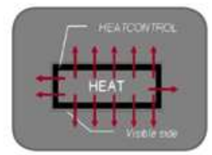
self-cleaning surfaces

enhanced aesthetics

increased corrosion resistance

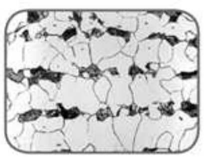


easy manufacturing: forming, painting, glueing, enamelling,...



heat transfer coatings

Application technology

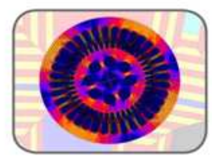


smart materials selection

structural design of components

welding

metal sheet rapid prototyping



FEM simulations: forming, electro-magnetic, heat,...

product safety (risk assessment of welding fumes, CrVI, VOC,...)

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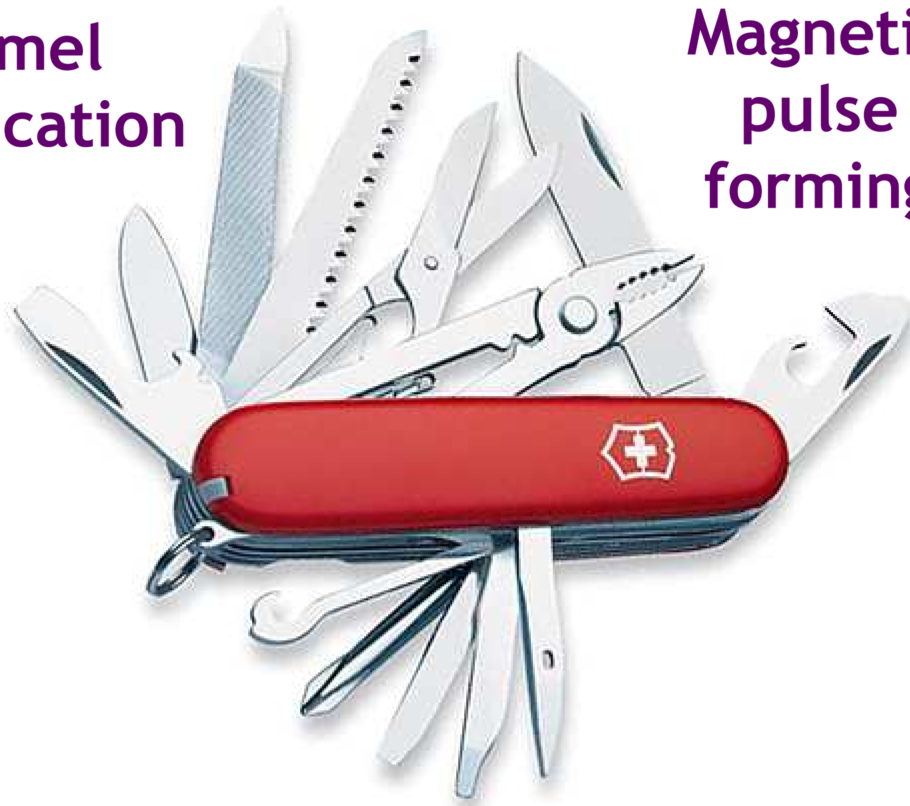
Enamel solidification

Magnetic pulse forming



Vortex induced vibrations

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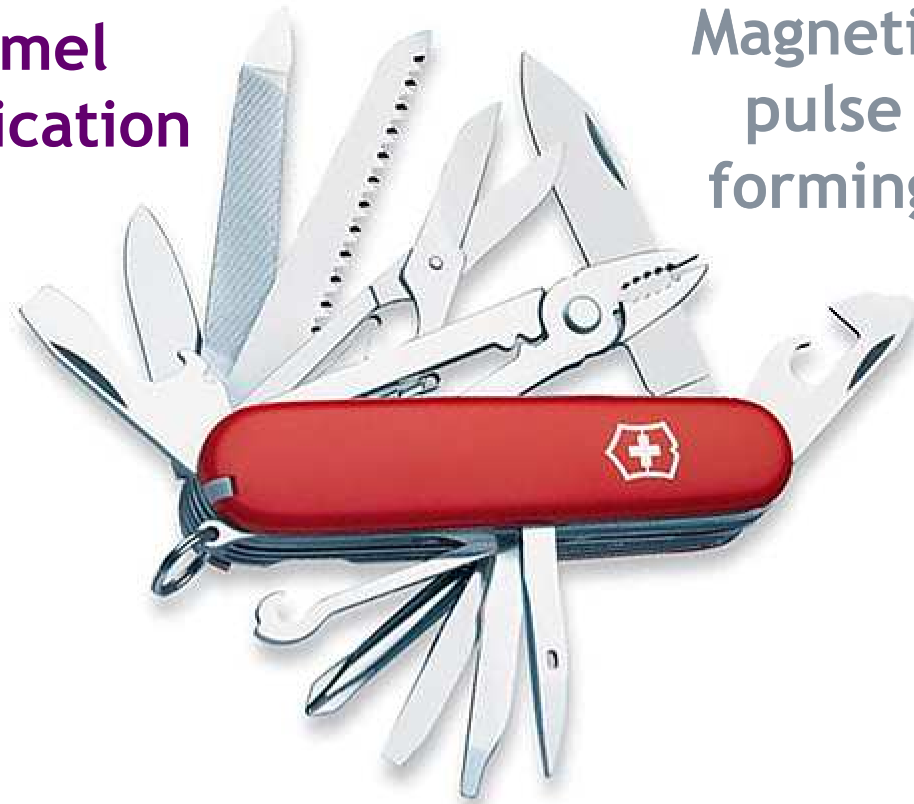


Vortex induced vibrations

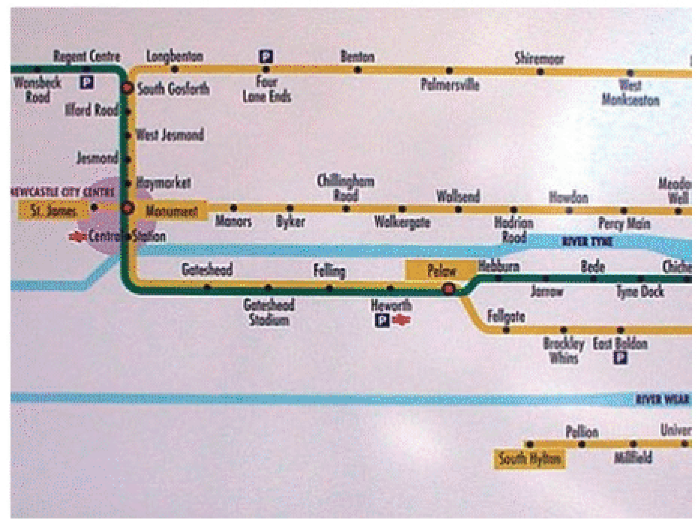
Enamelled Steel Parts

Enamelled Steel Parts

Facade

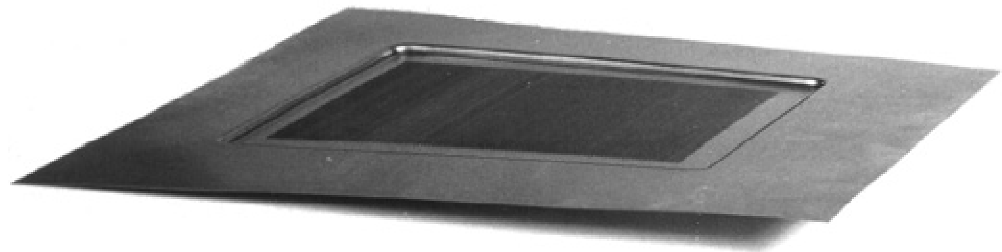
Tunnels

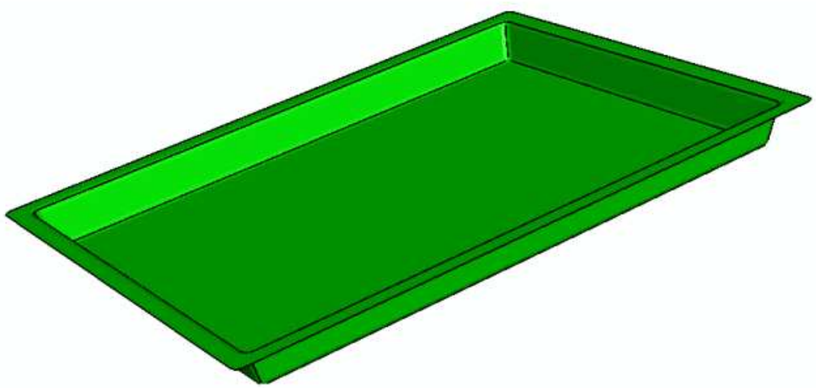
Underground

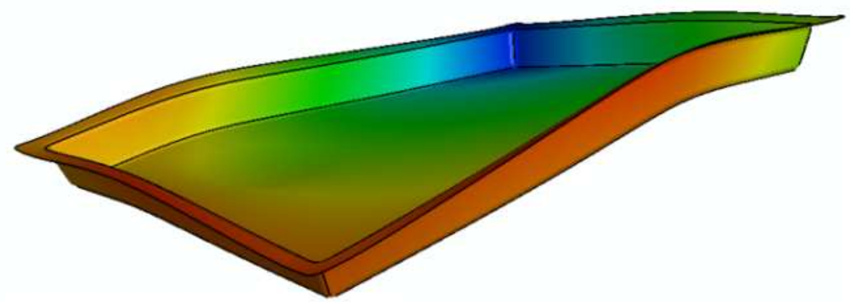


Signs

Thermal Distortion in Enamelled Steel Parts

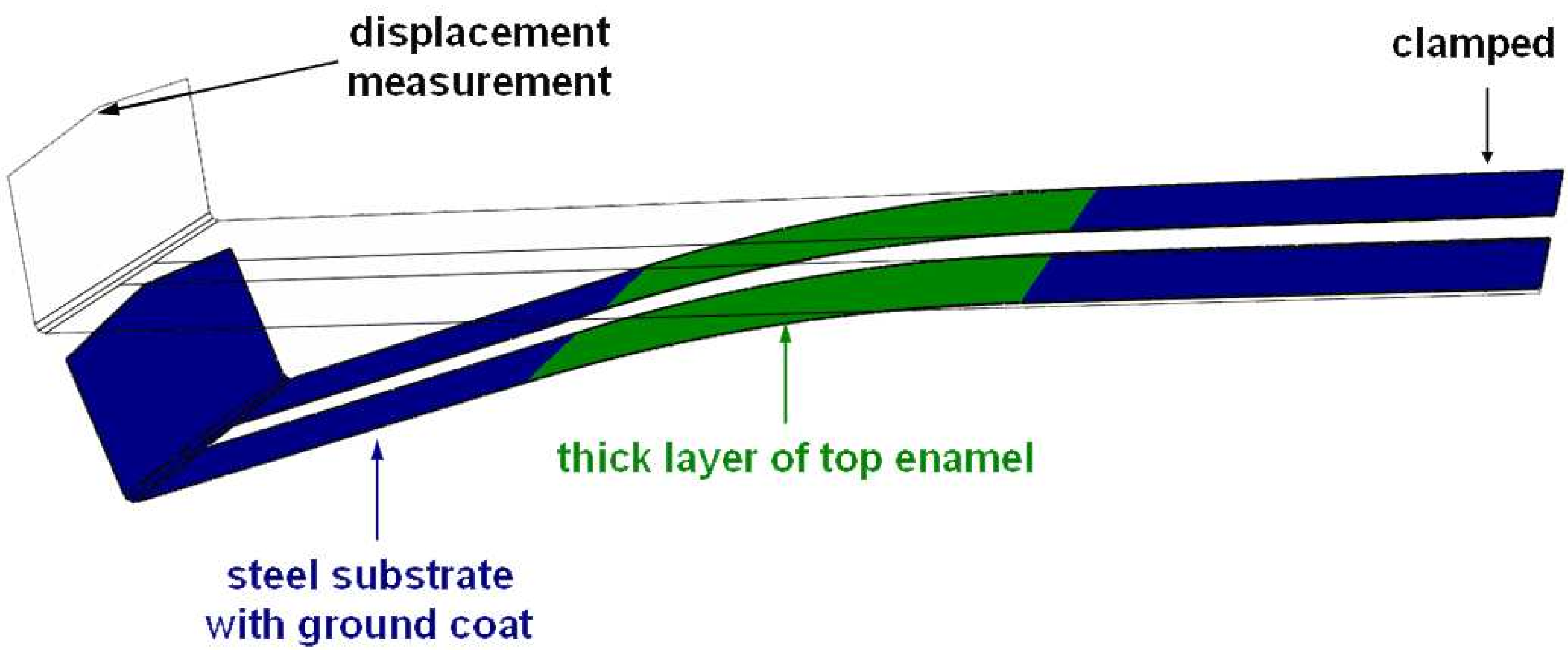






Klotz test to measure thermal distortion

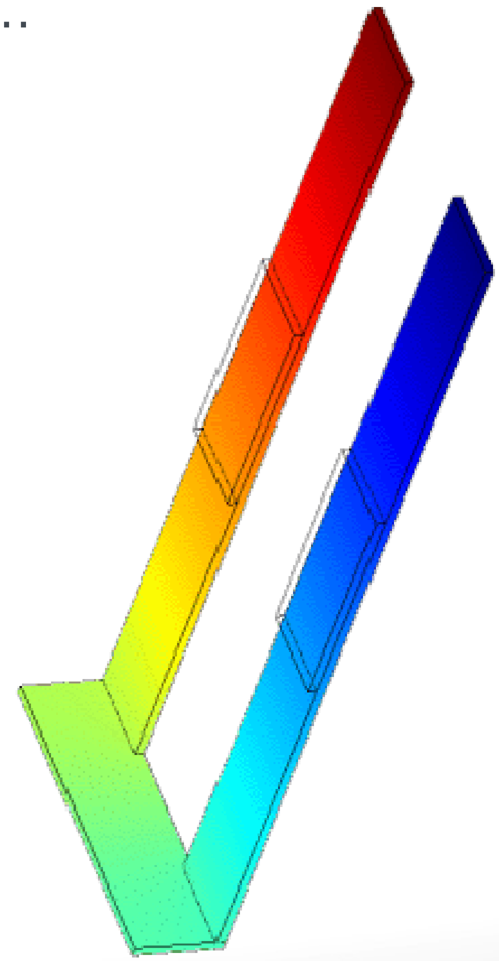
- Steel specimen is coated with ground enamel (both sides)
- One thick layer of top enamel is applied at one side
- Sample is heated, and temperature/displacement are measured



Multiphysics simulation of vitreous enamelling

- Conductive Media DC Mode to calculate distribution of electric current in the specimen…

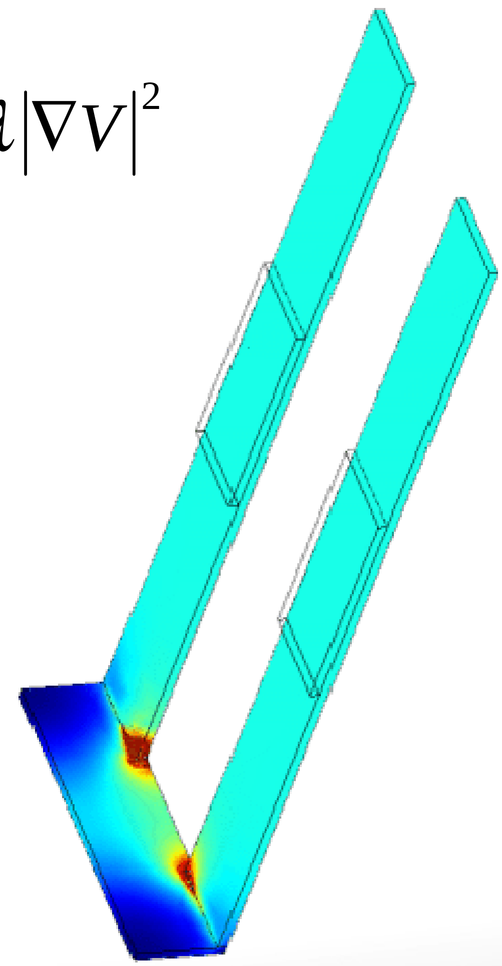
$$-\nabla\cdot\left(\lambda\nabla V - J^{ext}\right) = Q_j$$



Multiphysics simulation of vitreous enamelling

- …Obtained current acts as coupling variable to calculate the resistive heating...

$$-\nabla \cdot \left(\lambda \nabla V - J^{ext}\right) = Q_j \longrightarrow Q_{th} = \lambda \left|\nabla V\right|^2$$



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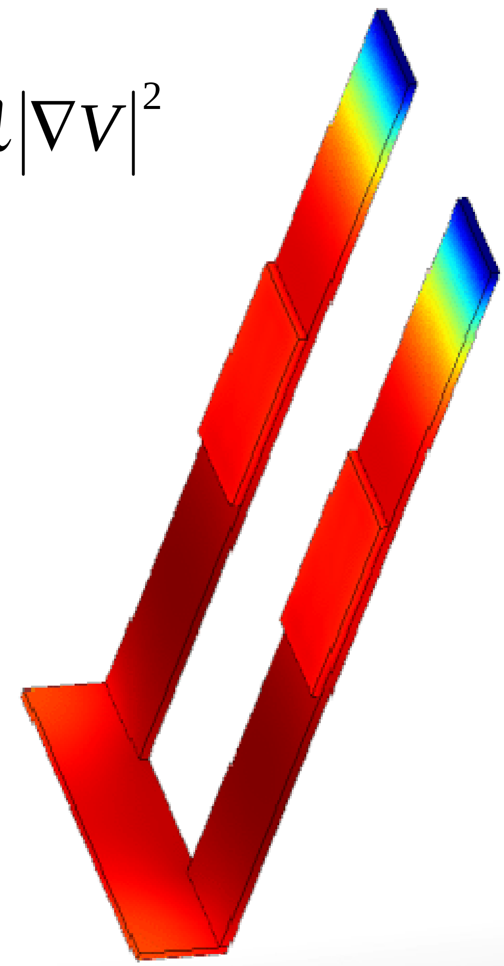
Multiphysics simulation of vitreous enamelling

- Which is the source term for the transient conductive heat equation…

$$-\nabla \cdot \left(\lambda \nabla V - J^{ext}\right) = Q_j \longrightarrow Q_{th} = \lambda \left|\nabla V\right|^2$$

$$\rho C \frac{\partial T}{\partial t} - \nabla \cdot \left(k \nabla T\right) = Q_{th}$$



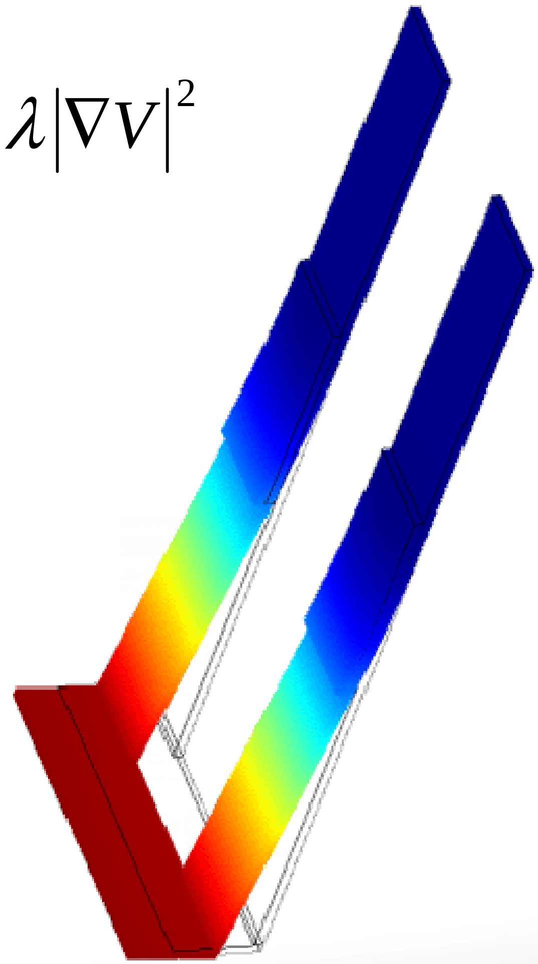
Multiphysics simulation of vitreous enamelling

- …Finally, thermal deflection is governed by temperature field

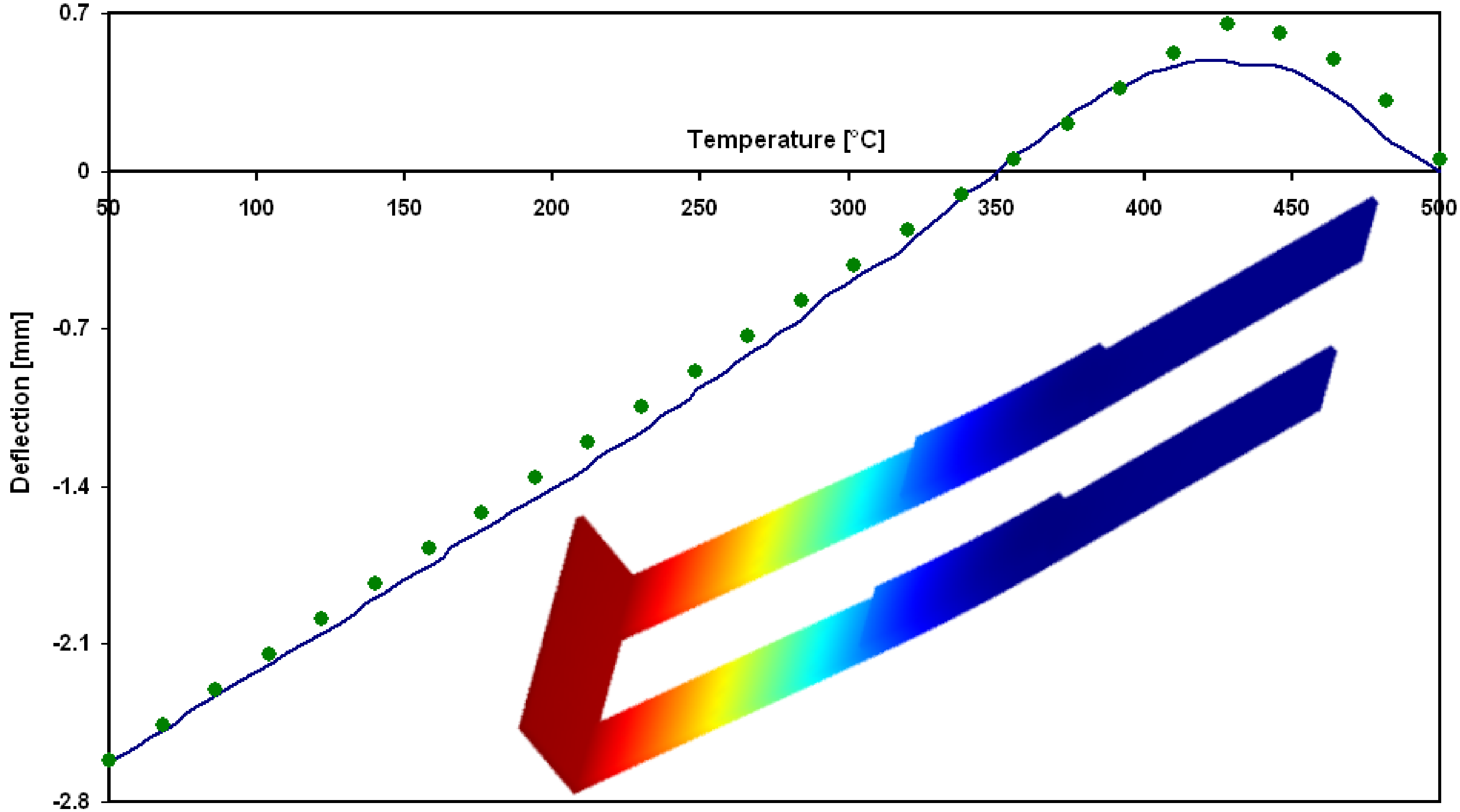
$$-\nabla \cdot \left(\lambda \nabla V - J^{ext}\right) = Q_j \longrightarrow Q_{th} = \lambda \left|\nabla V\right|^2$$

$$\rho C \frac{\partial \mathbf{T}}{\partial t} - \nabla \cdot \left(k \nabla \mathbf{T}\right) = Q_{th}$$

$$\frac{\delta(\mathbf{T})}{L} = \frac{L}{H} K \int_{T_N}^{\mathrm{T}} \left(\alpha_s(\tau) - \alpha_e(\tau)\right) d\tau$$



Multiphysics simulation of vitreous enamelling



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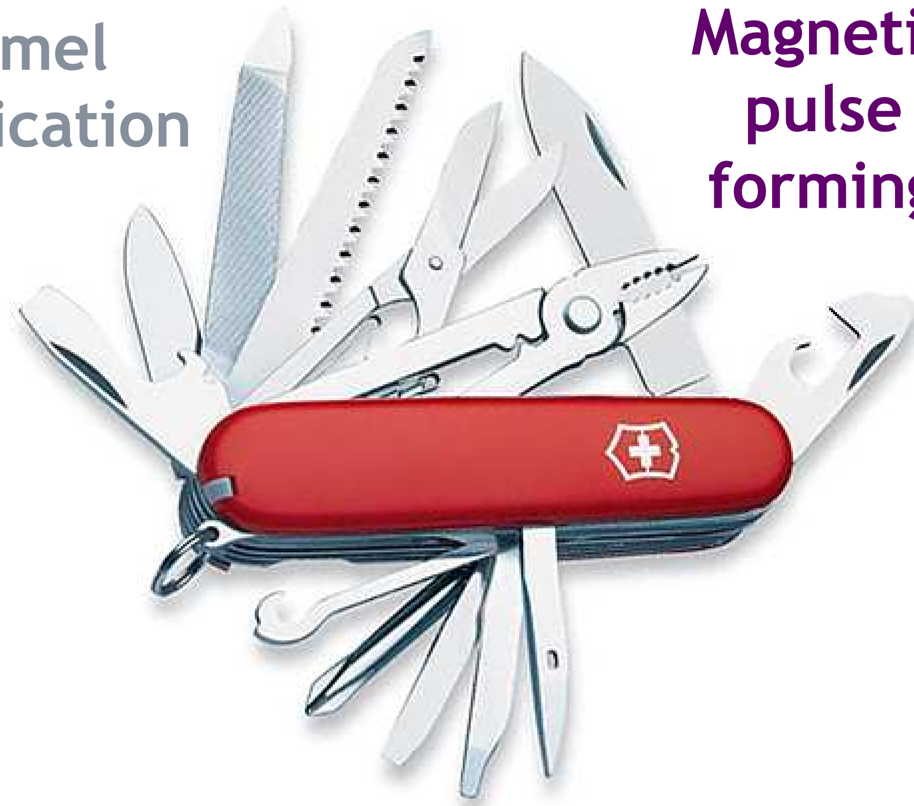
Enamel solidification

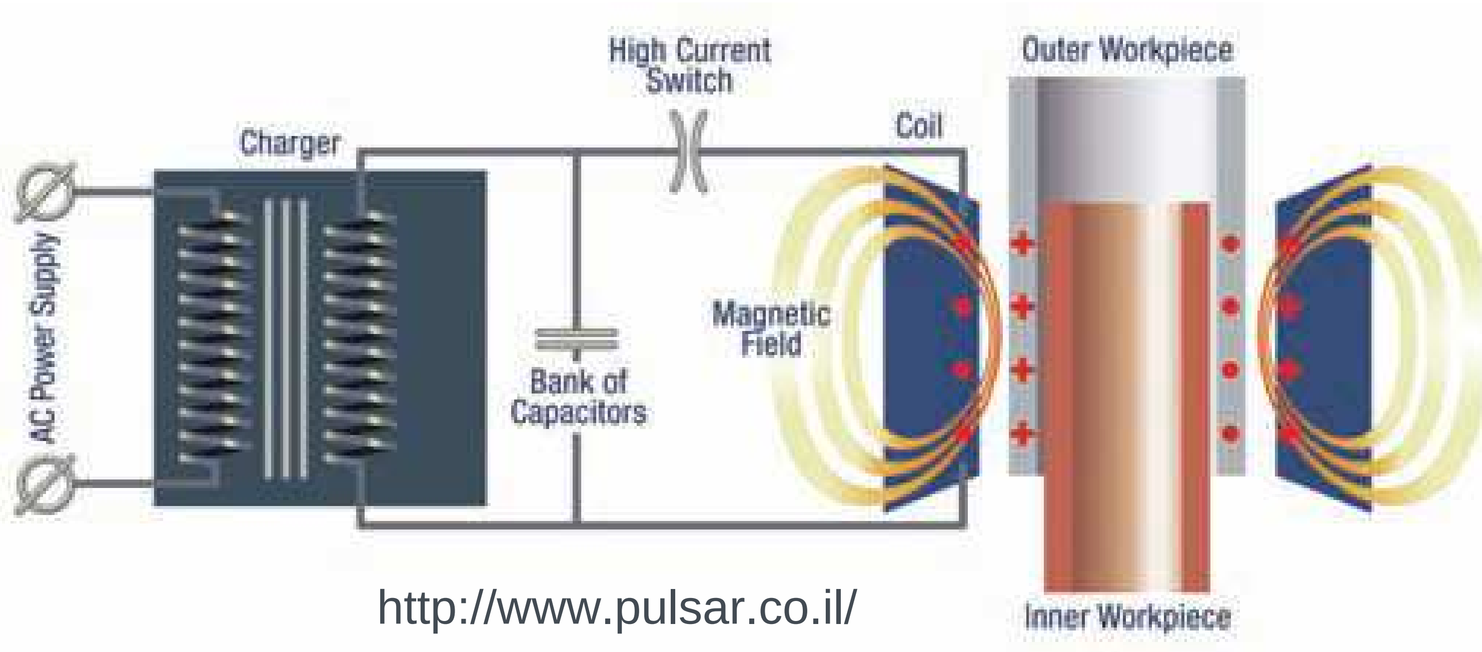
Magnetic pulse forming



Vortex induced vibrations

Magnetic Pulse Forming

- Magnetic Pulse Forming (MPF) is a high speed metal forming technique in which transient electric currents are generating magnetic forces to form metal workpieces



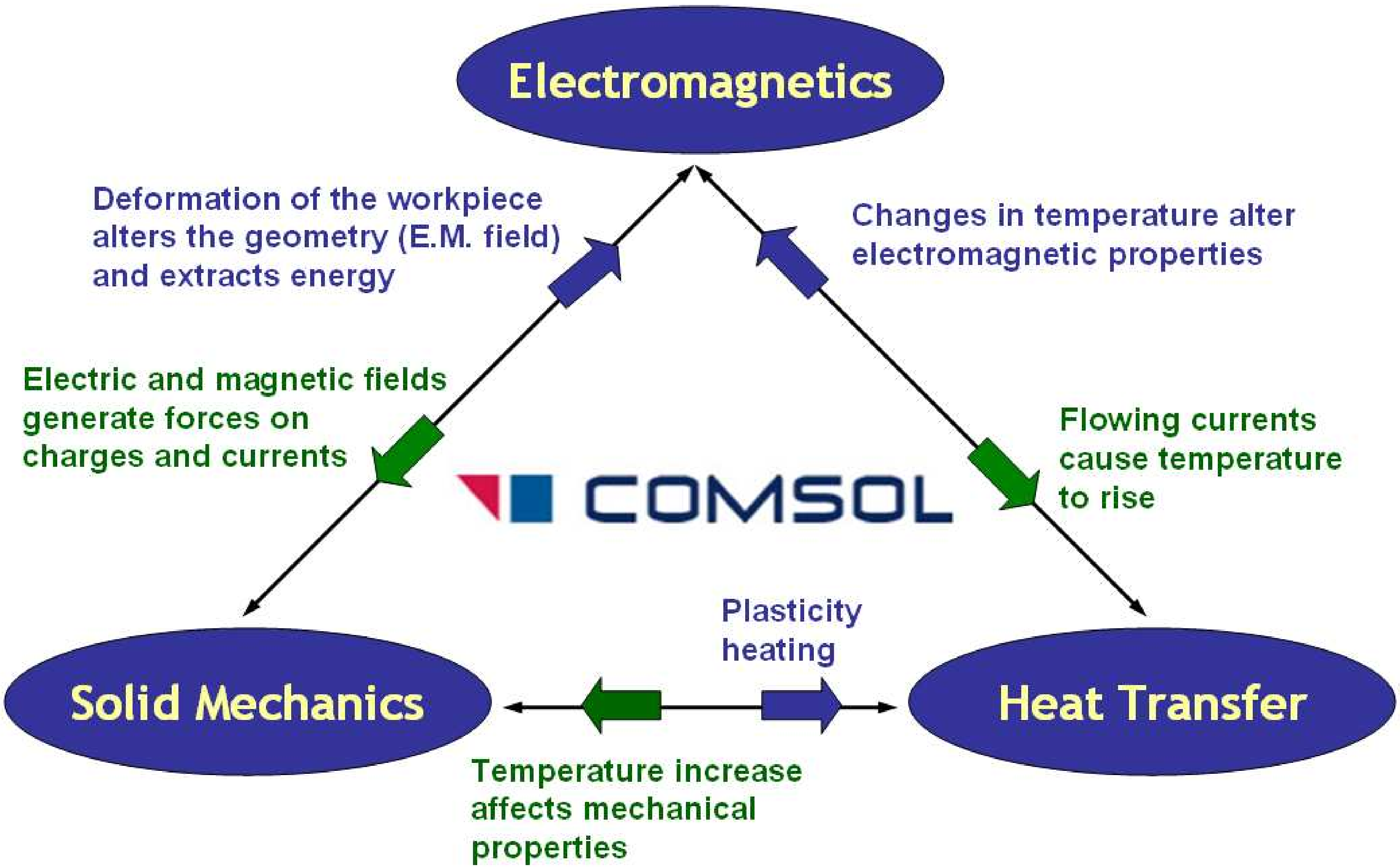
http://www.pulsar.co.il/

Numerical Modelling of MPF

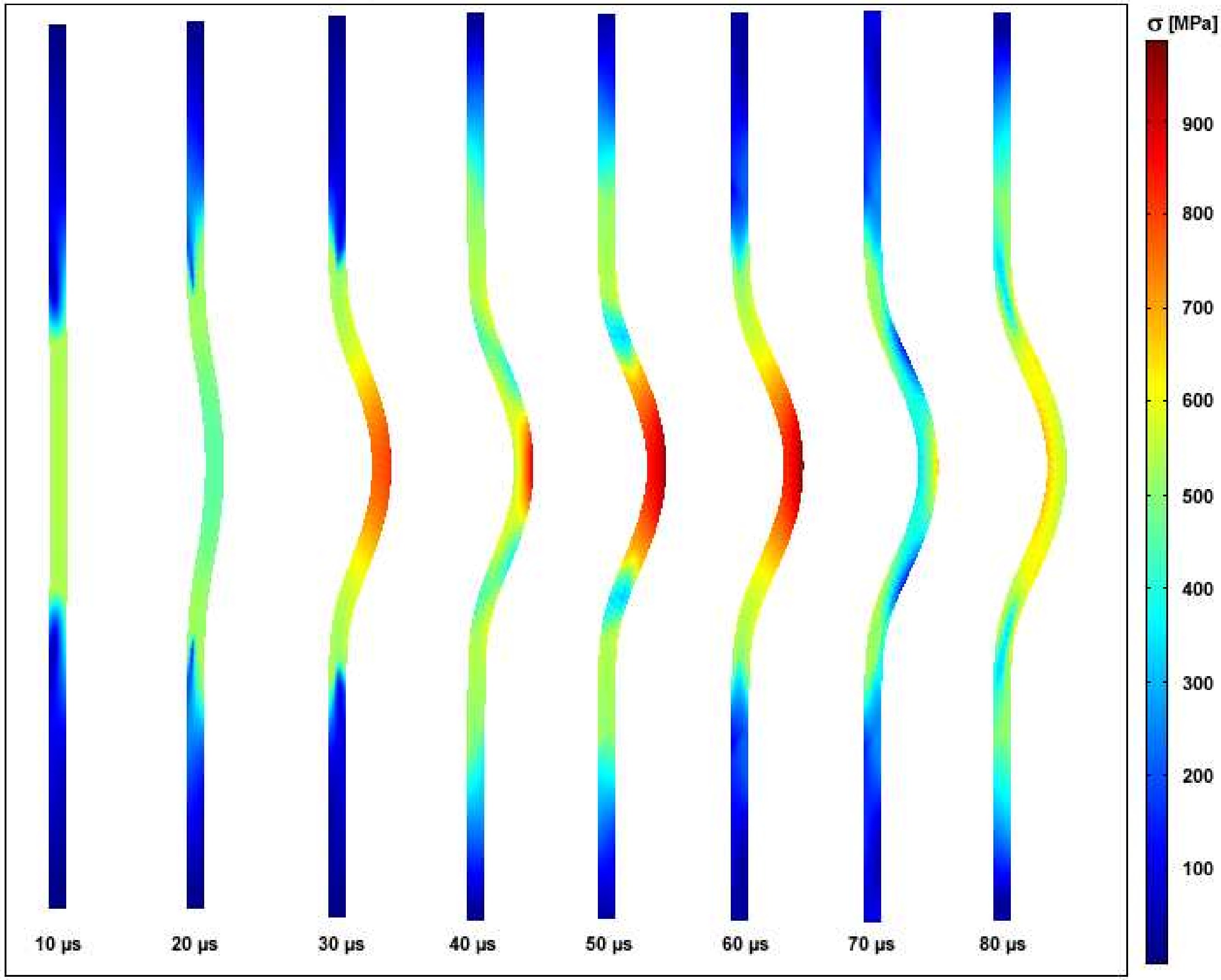
- Numerical model requires the simultaneous solution of
  - The electric circuit
  - The electromagnetic equations
  - The temperature distribution
  - The mechanical response

- Highly complex and strongly coupled problem, calling for
  - multiphysics capabilities
  - weak PDE formulation
  - direct coupling

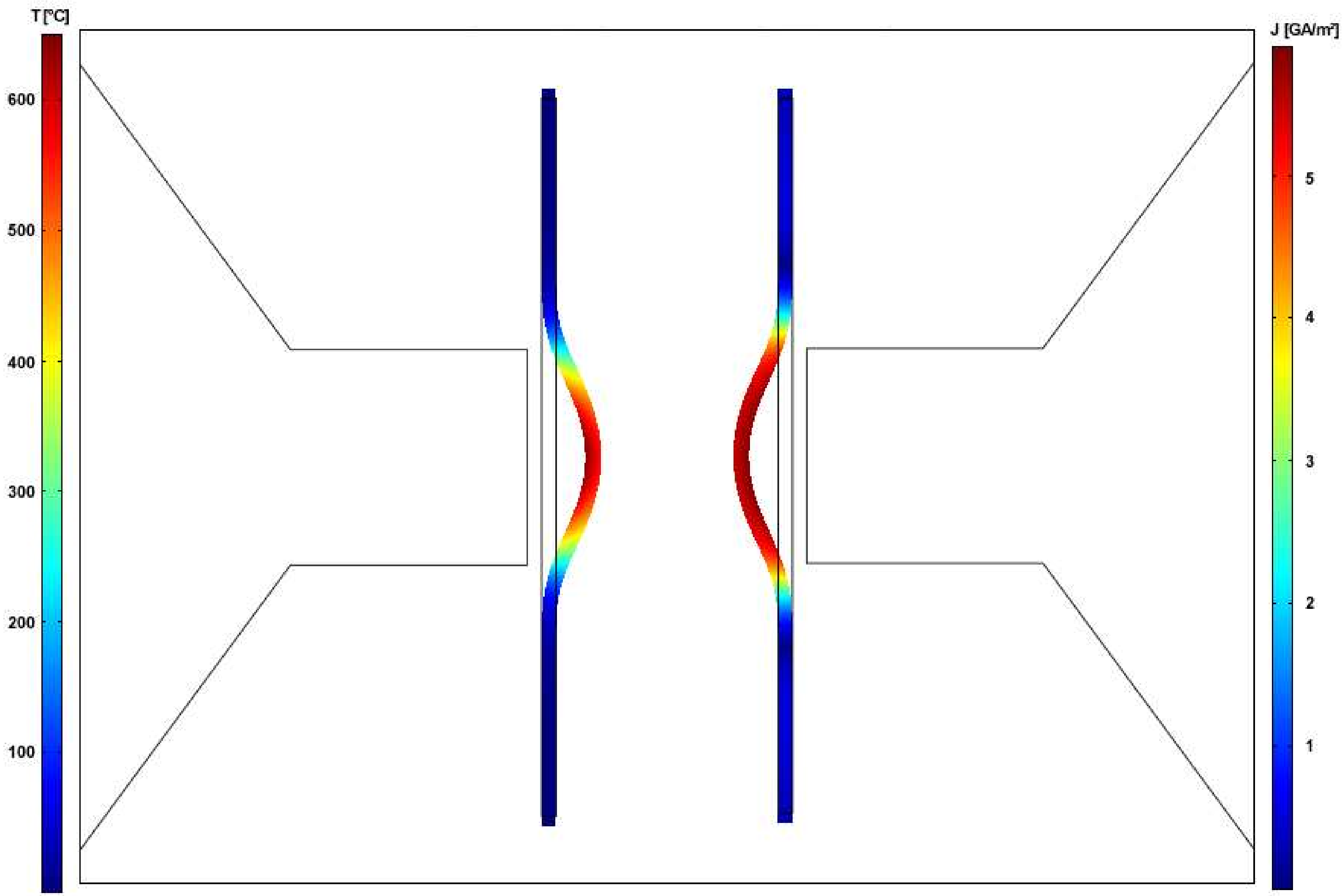
Numerical Modelling of MPF



Free deformation of a steel tube



Free deformation of a steel tube



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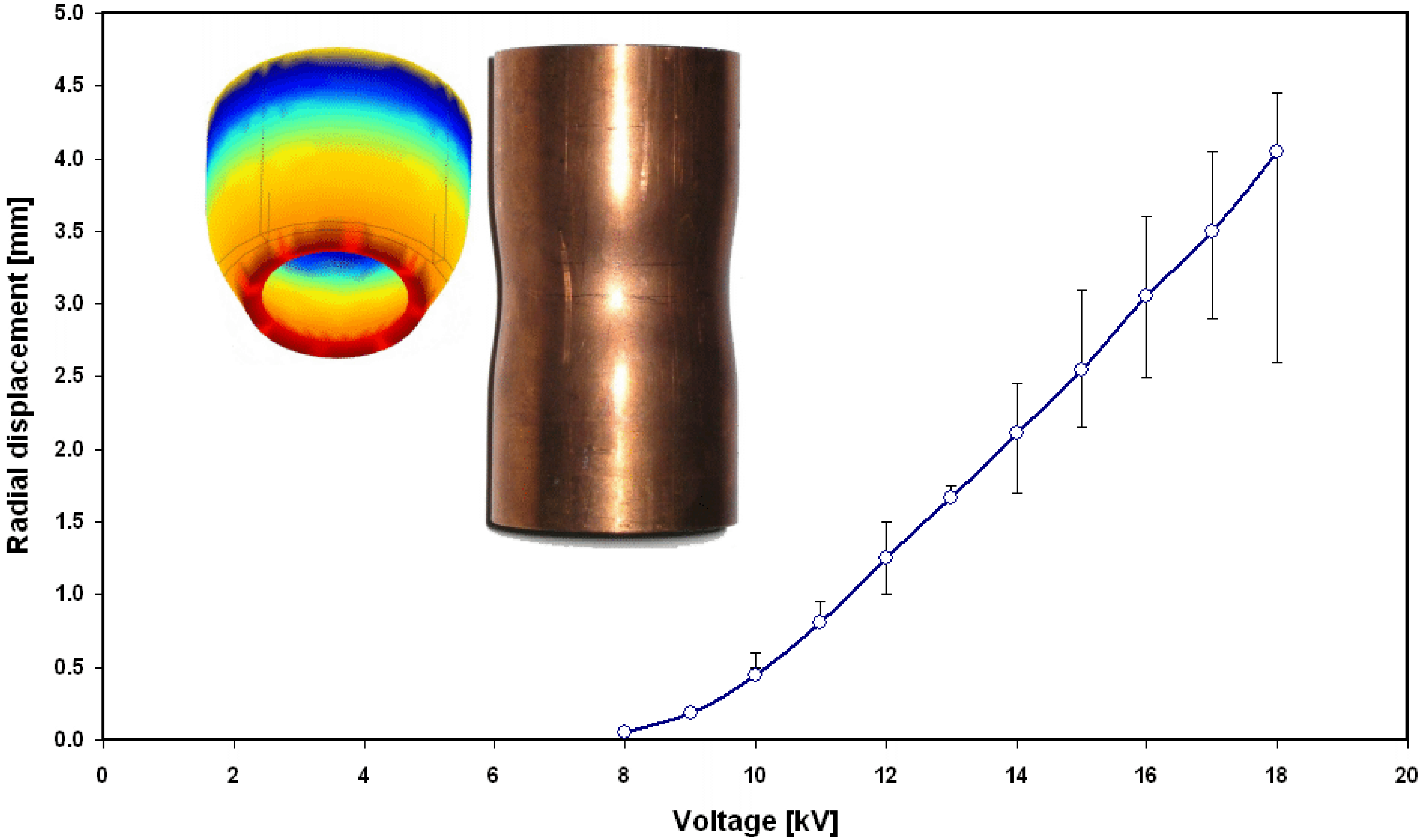
Free deformation of a steel tube



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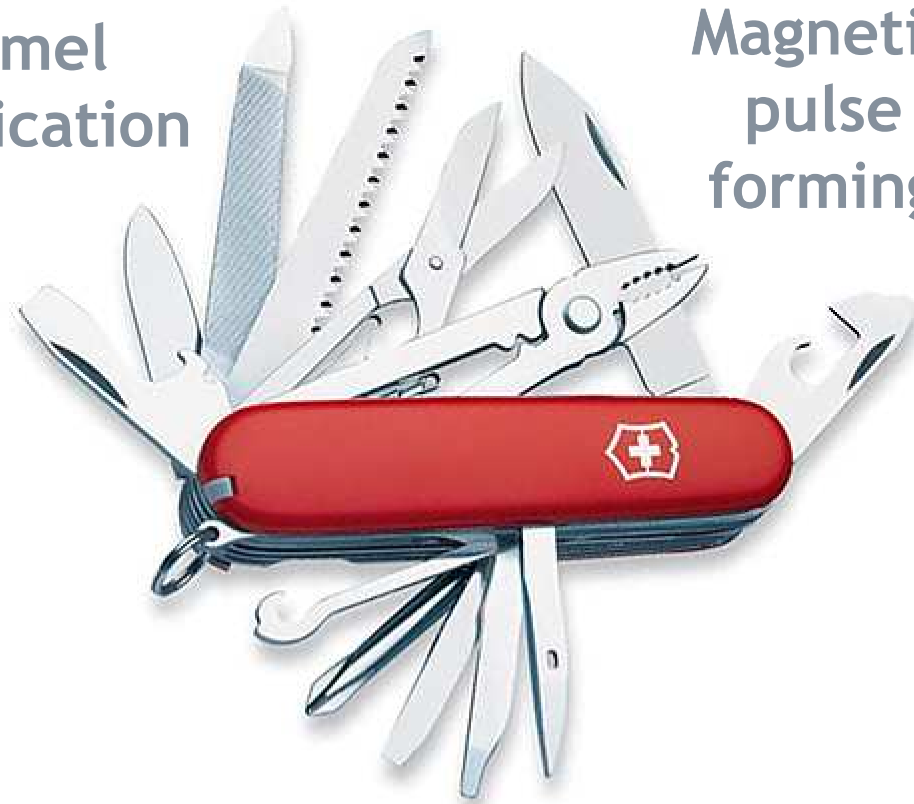
Enamel solidification

Magnetic pulse forming



Vortex induced vibrations

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Vortex shedding

- Even moderate currents can induce vortex shedding, alternately at the top and bottom of the pipeline, at a rate determined by the flow velocity
- Each time a vortex sheds, a force is generated in both the in-line and cross-flow direction, causing a multi-mode vibration
- This vortex induced vibration can give rise to fatigue damage of subsea pipeline spans, esp. in the vicinity of the girth welds

Flow patterns past a pipeline

- Flow regime dependent on Reynolds number

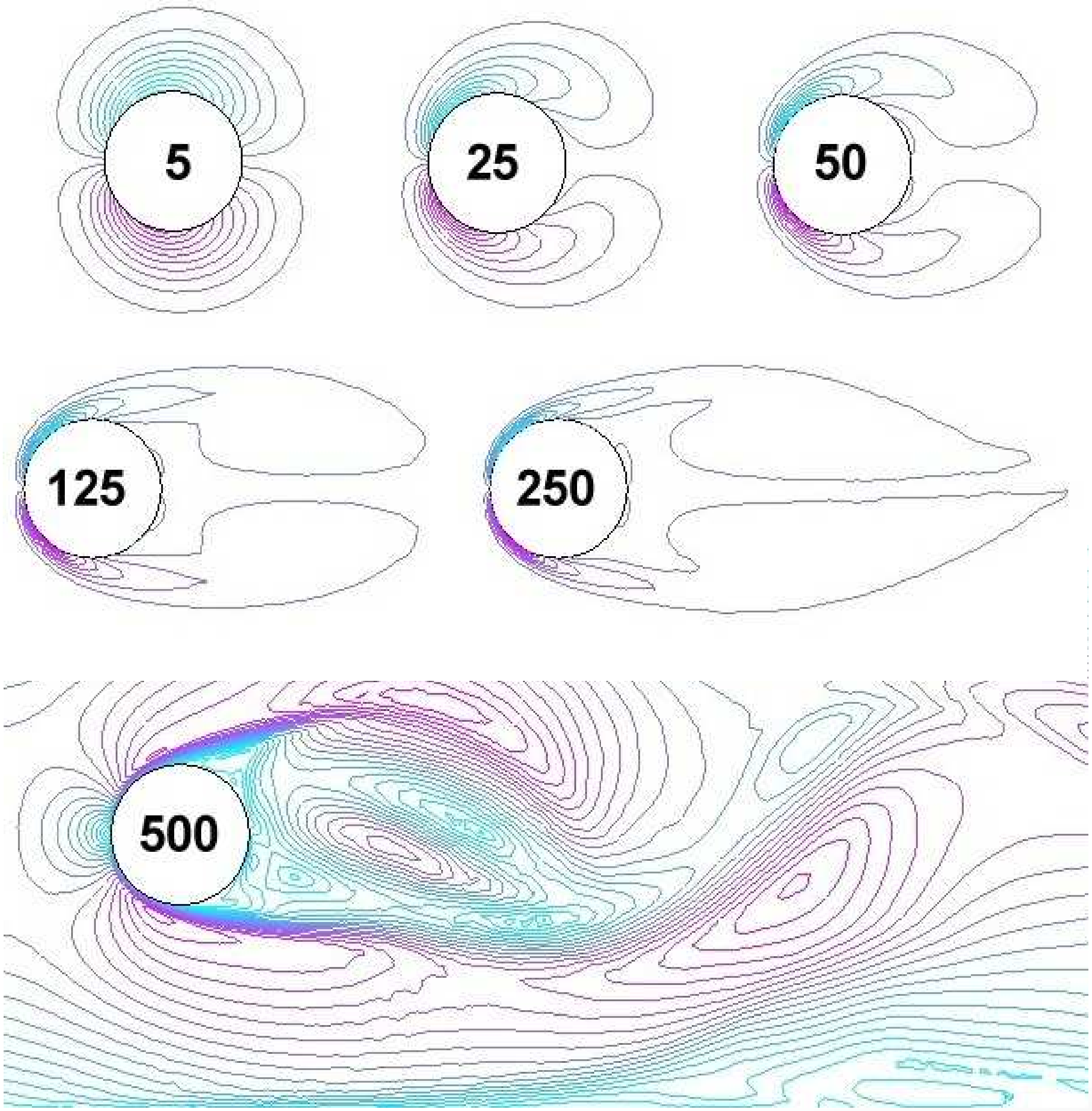
$$\mathrm{Re} = \frac{U\,D}{\upsilon}$$

- Vortex shedding governed by Strouhal number

$$St = \frac{f_s\,D}{U}$$

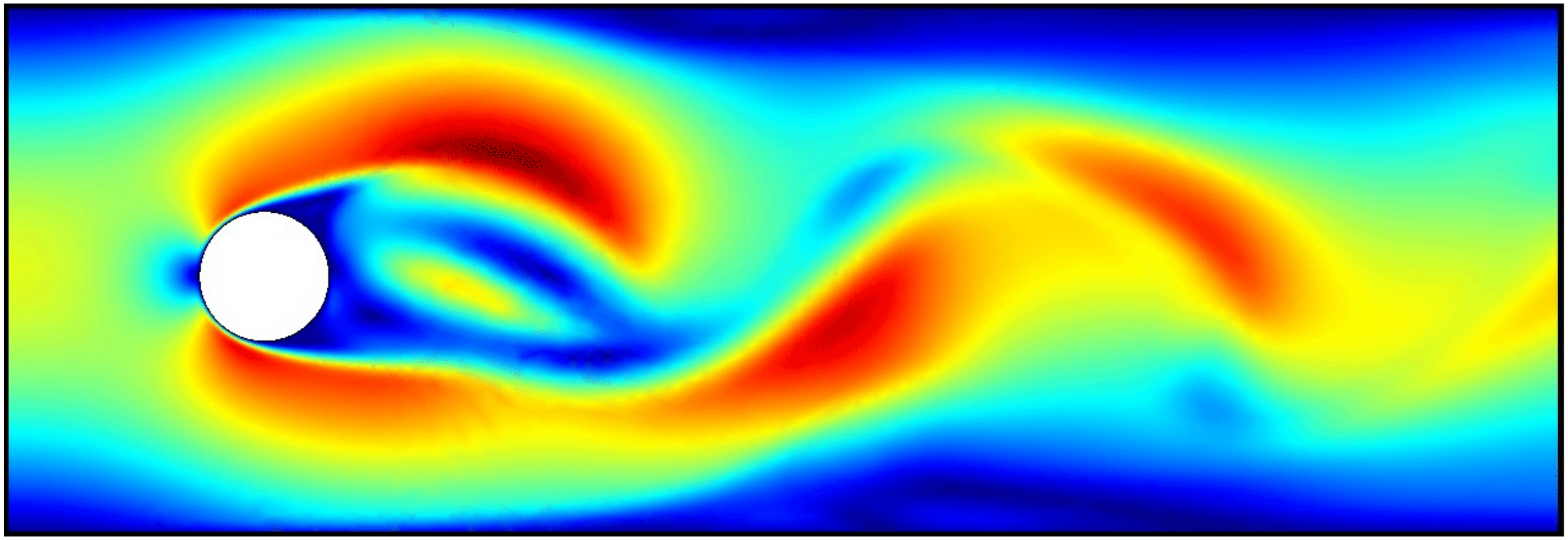
  - Fluid flow velocity U
  - Outer diameter D
  - Kinematic viscosity υ
  - Shedding frequency f_s

Flow patterns predicted by Comsol



Vortex shedding predicted by COMSOL

- For a Reynolds number Re > 300, a Von Karman vortex street appears with a stable frequency and amplitude



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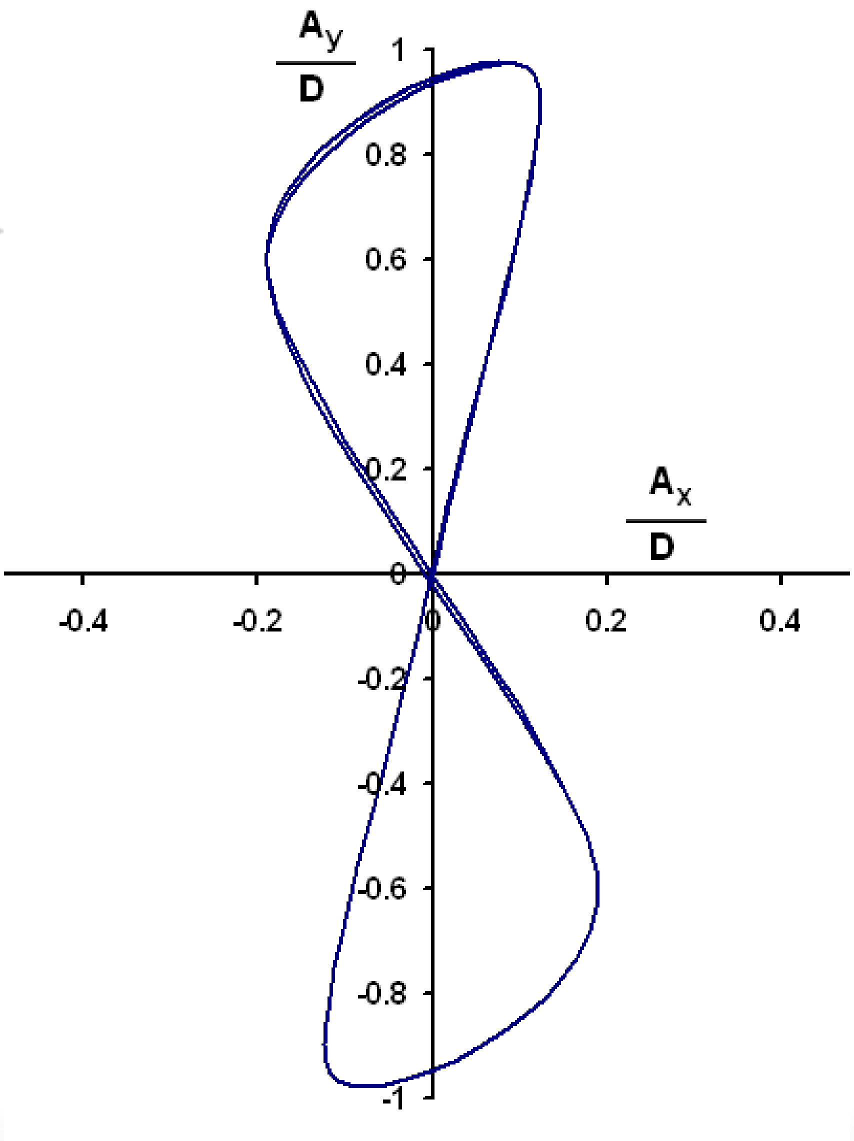
Vortex induced vibrations



- Submarine pipelines, subjected to vortex induced vibrations, tend to trace an '8' shaped motion
- These motions can induce fatigue damage in the pipe itself, the girth welds or the coating
- How can we avoid (or at least reduce) the effects of vortex induced vibrations?

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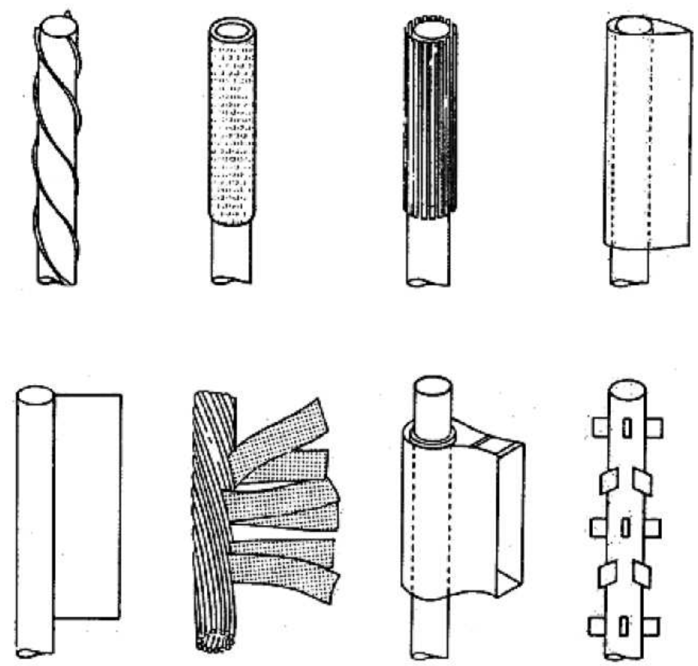
Mitigation measures

- Several mitigation measures have been developed to avoid or reduce the effects of vortex induced vibrations:

  - Control cylinders
  - Helical strakes
  - Fairings
  - Splitters
  - Spoilers
  - Others

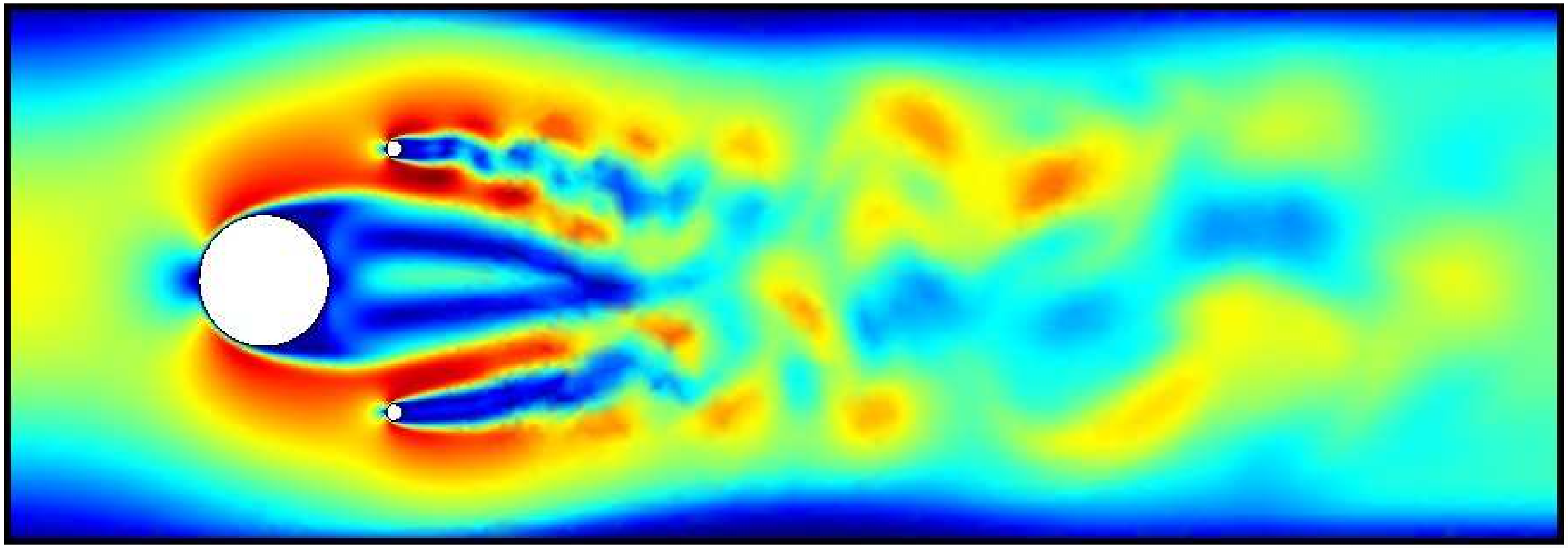


- COMSOL Multiphysics provides an elegant numerical tool to compare these measures, and evaluate their effectiveness

Control cylinders

- Control cylinders stabilize the near wake and

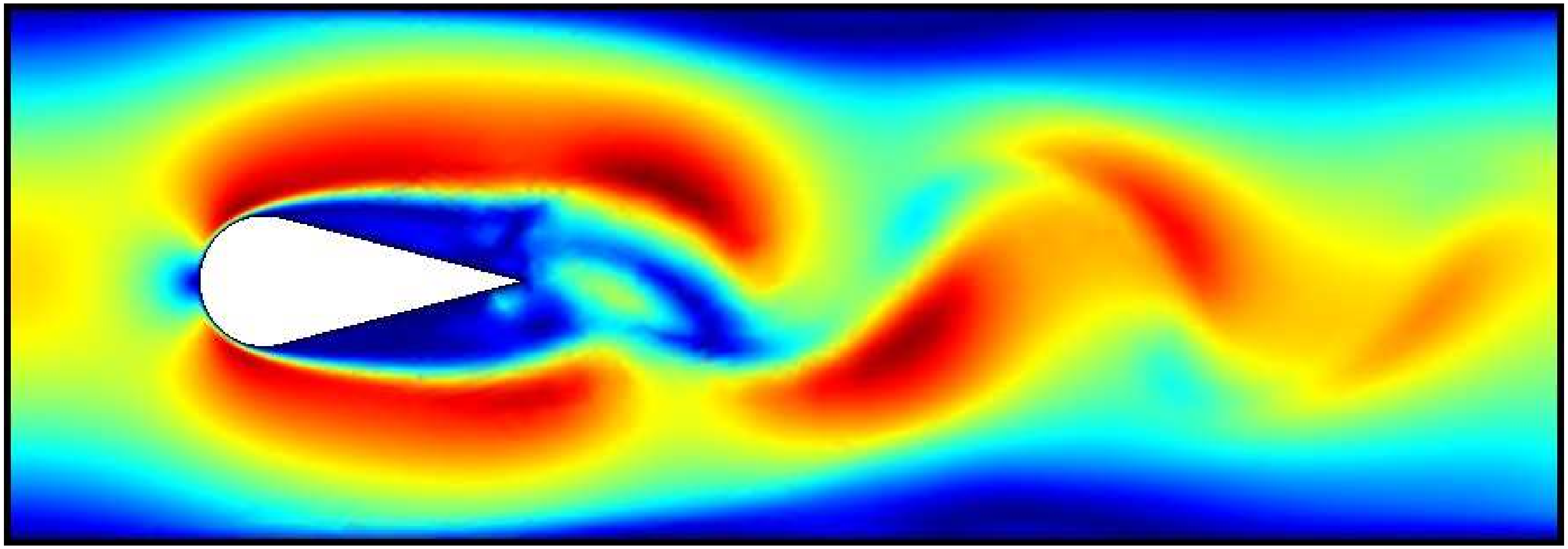
  cause the wake to be essentially time-independent
- Resulting decrease in drag, and elimination of the fluctuating lift
- Only useful in unidirectional flows, and location is Re-dependent



Helical strakes versus fairing

- Helical strakes disrupt the correlation of vortex shedding along the pipeline span, hence reducing the vortex strength and the magnitude of the oscillatory lift forces

- Fairings attempt to streamline the flow, in order to reduce the size of the vortices while they are adjacent to the cylinder



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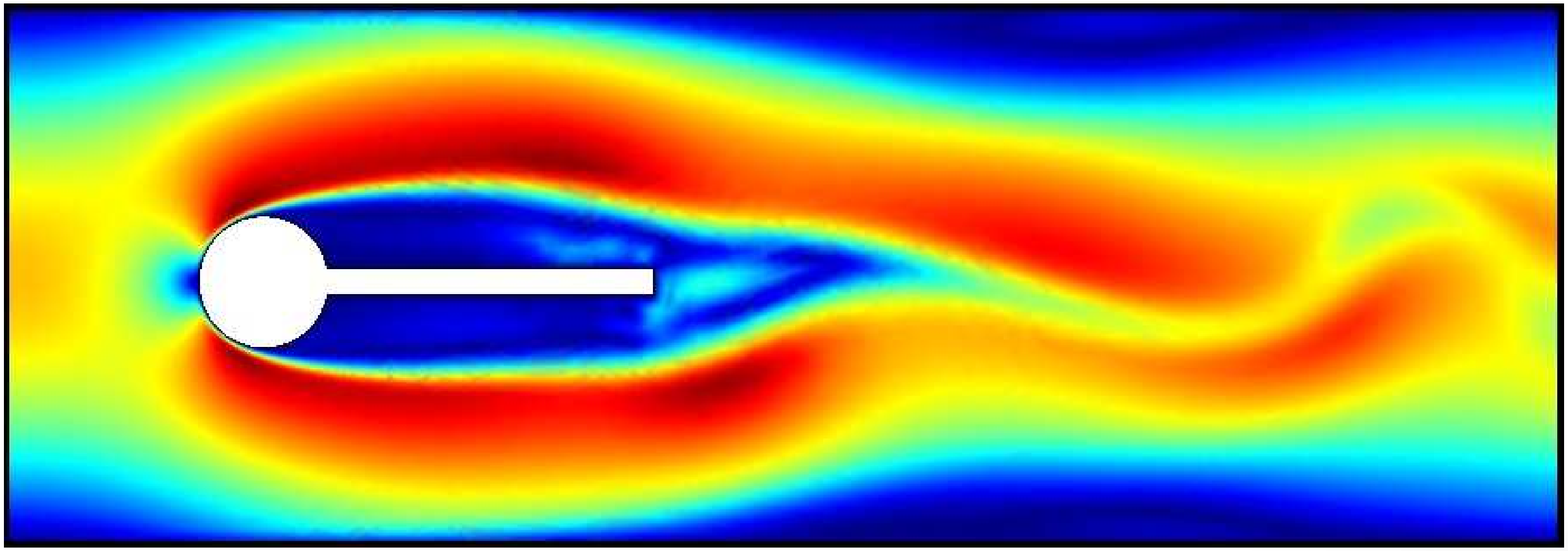
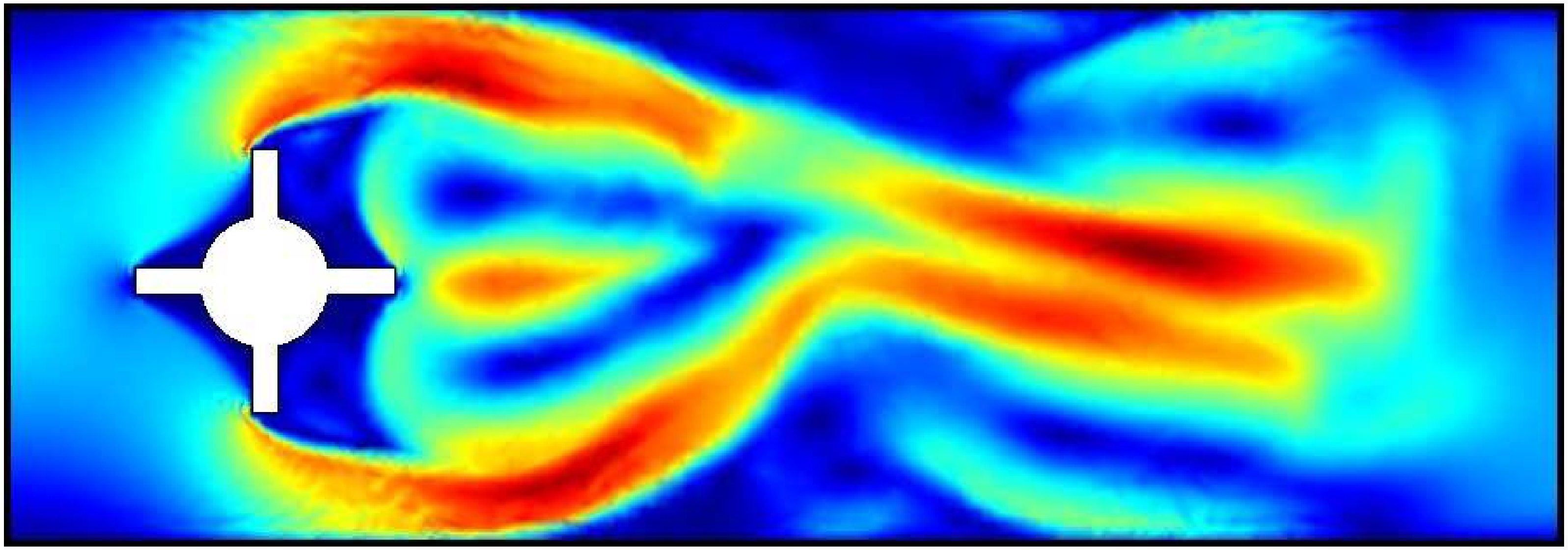
Splitters and spoilers

- Vortex shedding can be reduced by either splitting or spoiling the turbulent flow in the pipeline wake



Splitters and spoilers

- Vortex shedding can be reduced by either splitting or spoiling the turbulent flow in the pipeline wake
- Note that spoiler plates can still be successfully applied when the flow is no longer unidirectional



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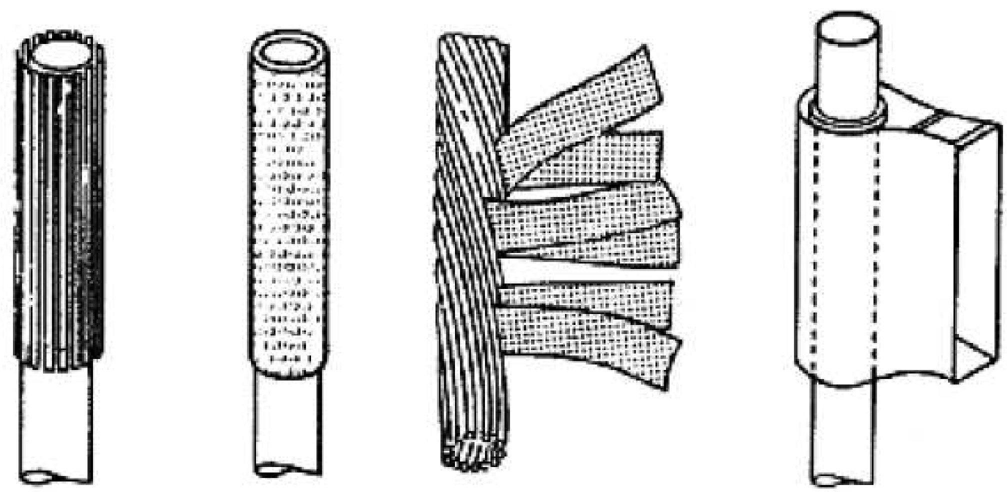
Other mitigation measures

- Several other add-on devices for suppression of vortex induced vibration exist, like
  - axial slats
  - shrouds
  - ribboned cables
  - pivoted guiding vanes



(a) (b) (c) (d)

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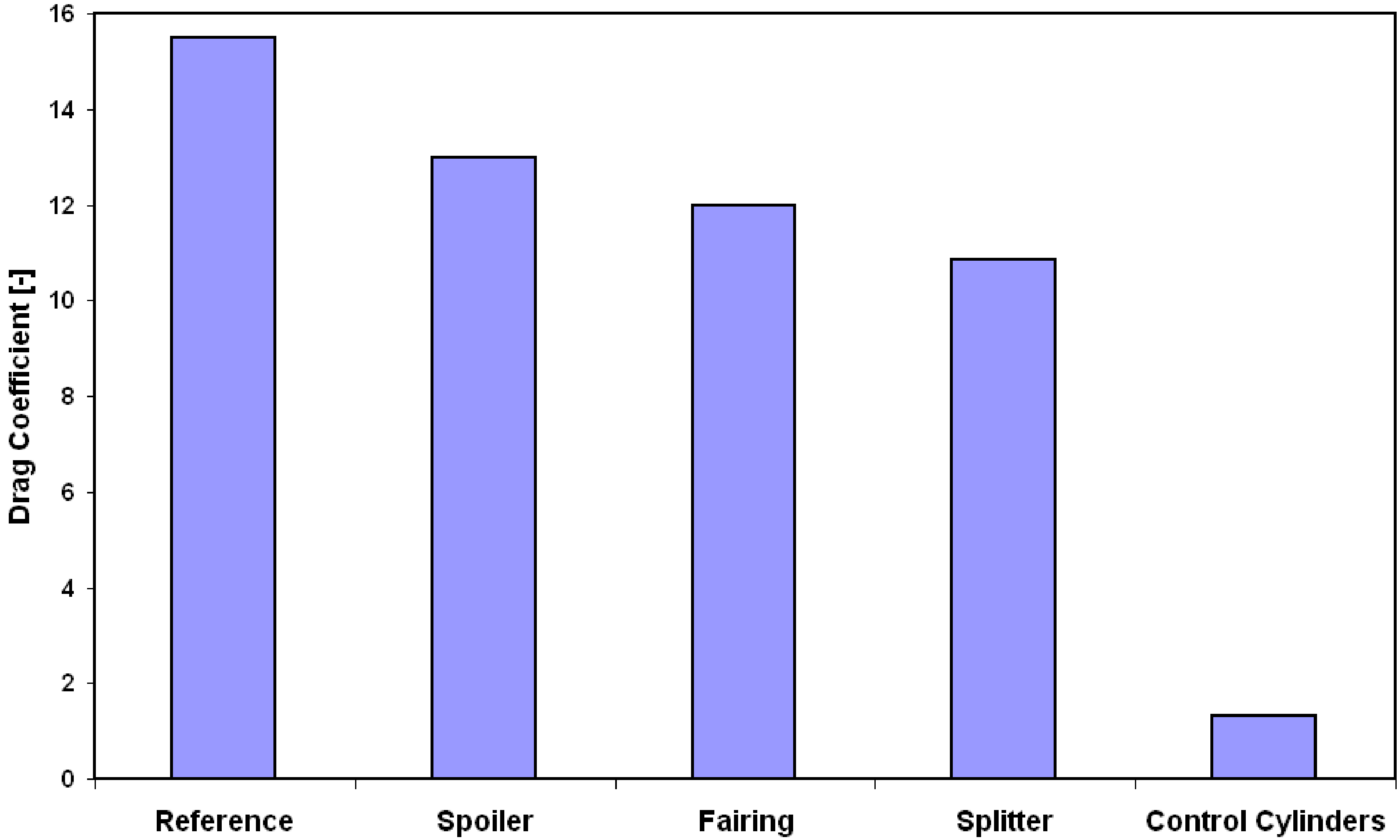
Comparing mitigation measures



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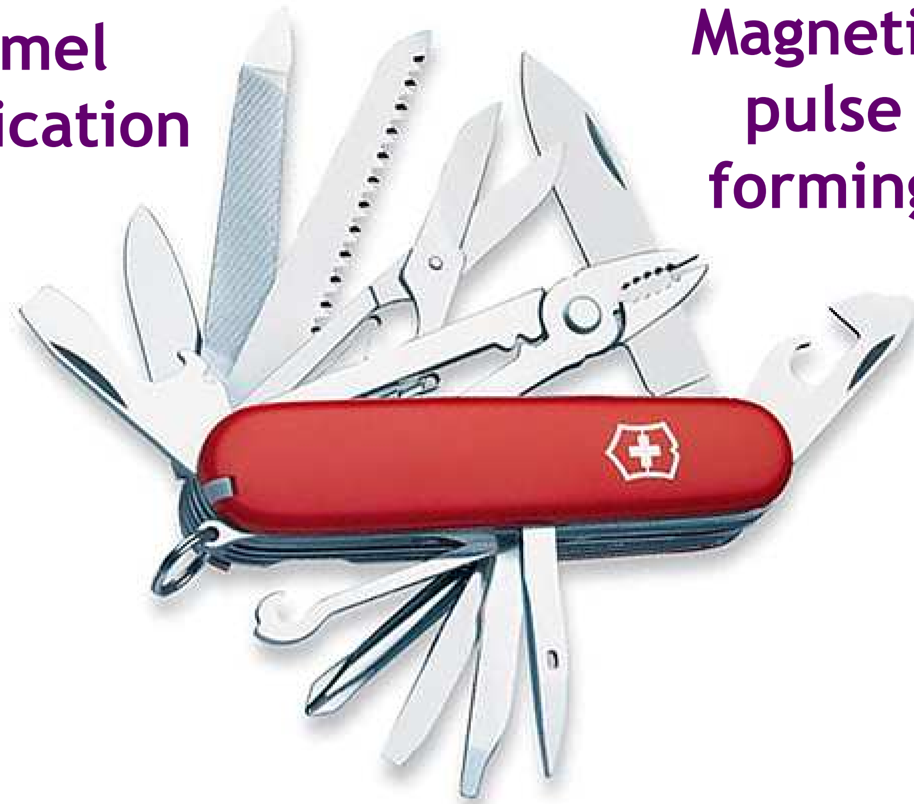
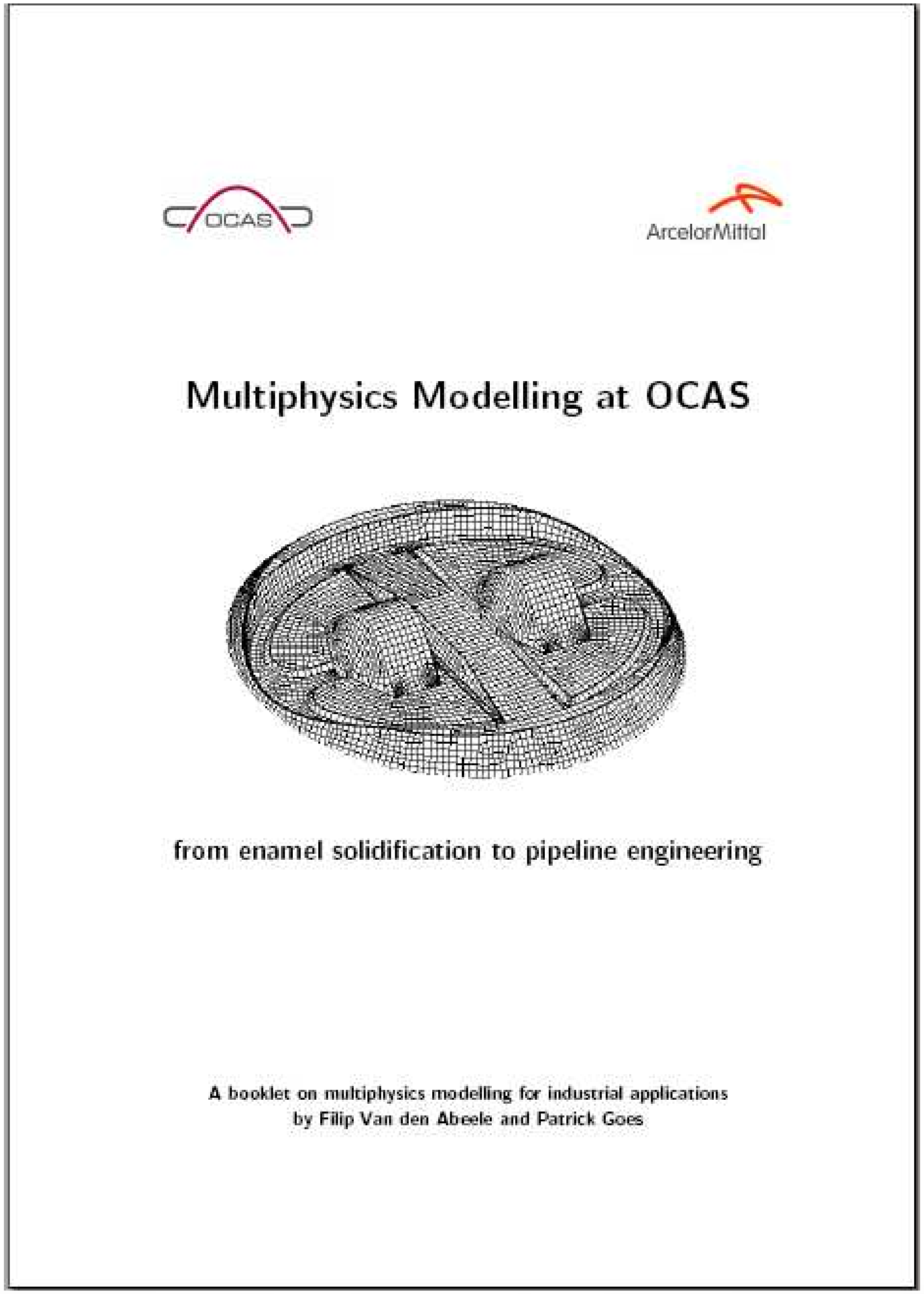
Enamel solidification

Magnetic pulse forming



Vortex induced vibrations


ArcelorMittal

Multiphysics Modelling at OCAS

from enamel solidification to pipeline engineering

A booklet on multiphysics modelling for industrial applications
by Filip Van den Abeele and Patrick Goes

- Enamel solidification
- Magnetic Pulse Forming
- Electromagnetic modelling of electric machines
- Vortex Induced Vibrations
- Model Identification for Orthotropic Materials
- and many more…

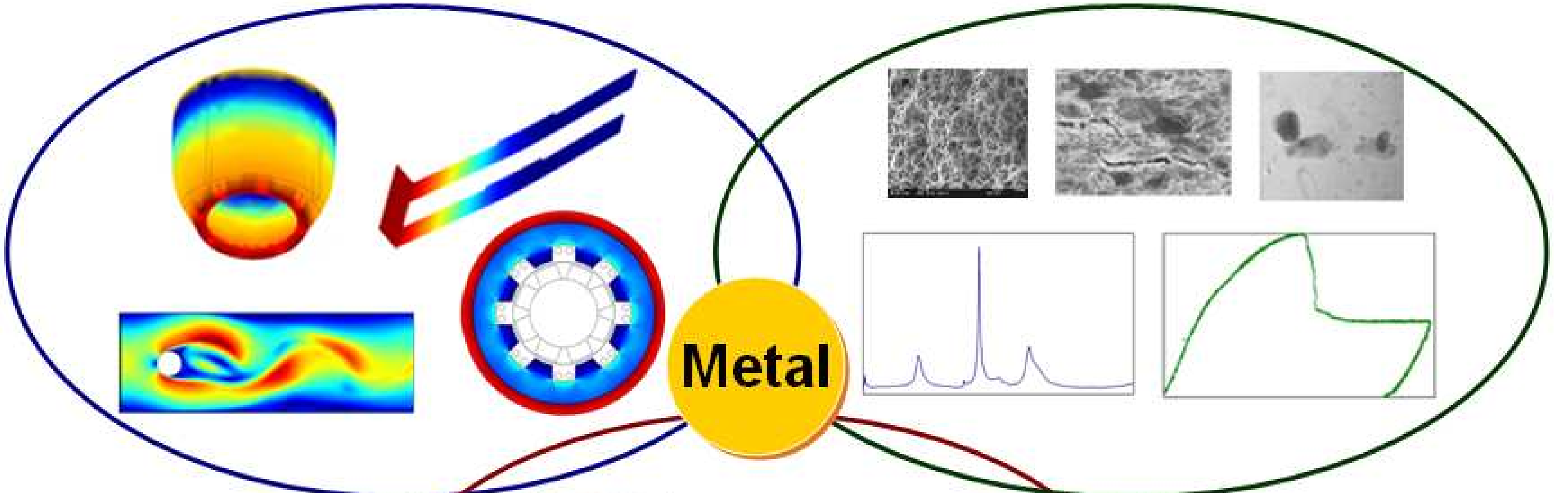
OCAS delivers added value

Steel design solutions

- ✓ Multiphysics modelling
- ✓ Fluid-structure interaction
- ✓ Electromagnetic simulations

Material characterisation

- ✓ Microstructure
- ✓ Precipitation
- ✓ Fracture surface



Material processing

- ✓ New chemistry
- ✓ Improved metallurgy
- ✓ Process optimisation

OCAS: we catalyze your growth!

OCAS NV

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