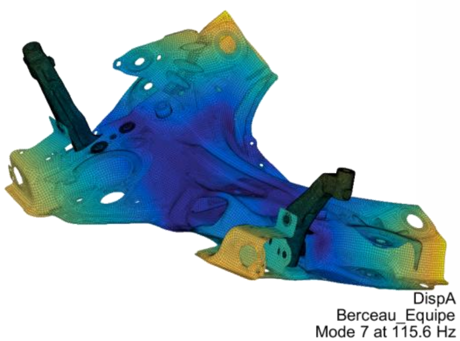
Modeling structures with piezoelectric materials in SDT

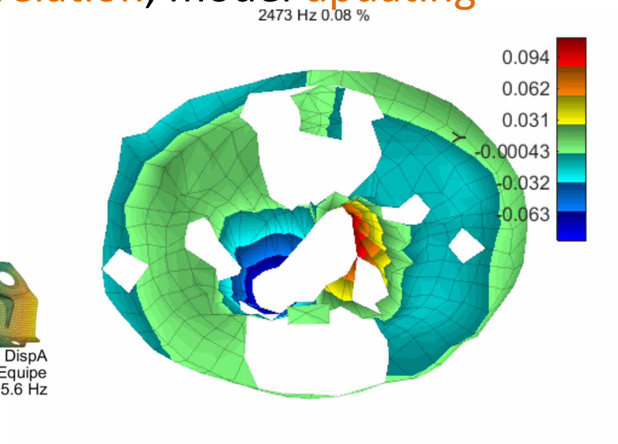
Arnaud Deraemaeker
Associate Professor – ULB BATir
aderaema@ulb.ac.be

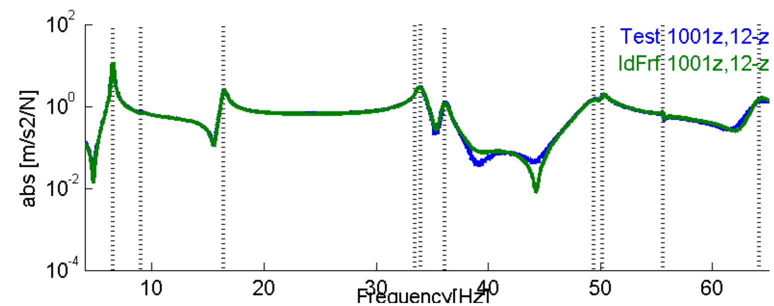
Etienne Balmès
CEO SDTools
balmes@sdtools.com

The Structural Dynamics Toolbox (SDT) for MATLAB

- FEM simulations
- System models (model reduction, state-space, active control)
- Experimental modal analysis
- Test/analysis correlation, model updating







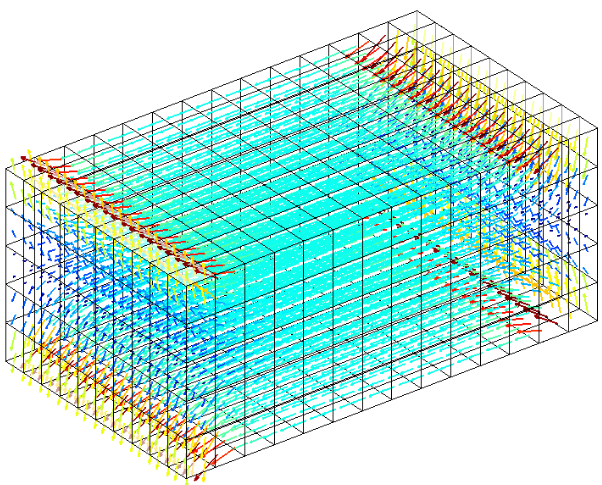
- General toolbox (programmatic access to all levels from pre-post to element level iterations)
- Custom applications (pantograph/catenary, visco, rotor, squeal, …)
- Customer base ensures maintenance: more than 750 licenses installed in 15 countries with users at Bosch, Boeing, Daimler/Chrysler, EADS, EDF, Ford, LANL, NASA, ONERA, PSA, Renault, Rockwell, Siemens, Sony, Valeo, etc.

The Structural Dynamics Toolbox (SDT) for Matlab

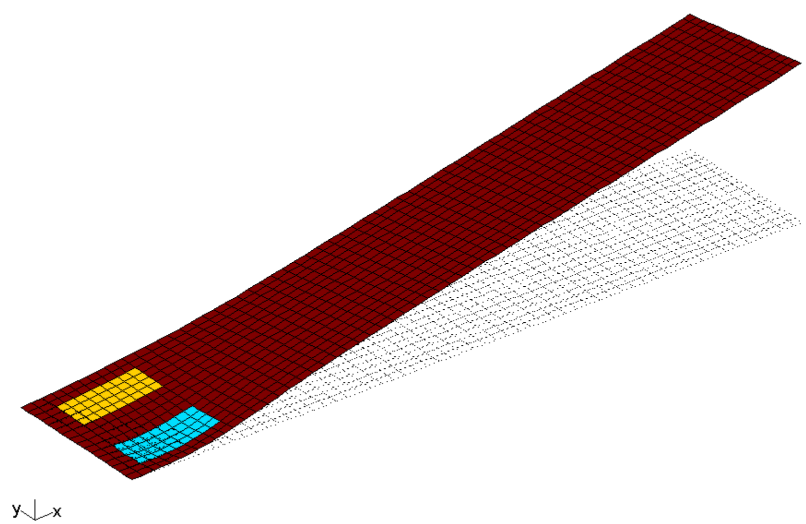
General 3-D Finite Element Modelling with an **open architecture** allowing easy user development of new multi-physics elements, ...

NEW The piezoelectric module

3D elements



Multi-layer plate elements



Main functionalities

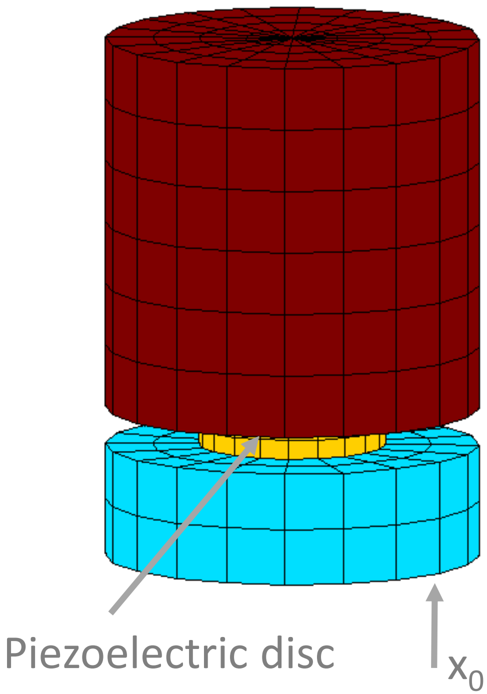
- **3D elements** for detailed modelling of piezoelectric systems such as actuators and sensors
- **Multi-layer plate elements** allowing to model plate structures equipped with thin piezoelectric transducers including piezocomposites such as Macro Fiber Composites (MFCs)
- Simple handling of **electrical boundary conditions** through the definition of electrodes. Combinations of voltage as well as charge can be applied and/or measured on the electrodes
- Advanced **visualisation tools** (electric field, electrode areas, charge density on electrodes)
- Static **periodic homogenization** of representative volume elements (RVE) for the modelling of piezocomposite transducers
- Possibility to export the model in the state-space format to be used for active control or passive shunt applications.

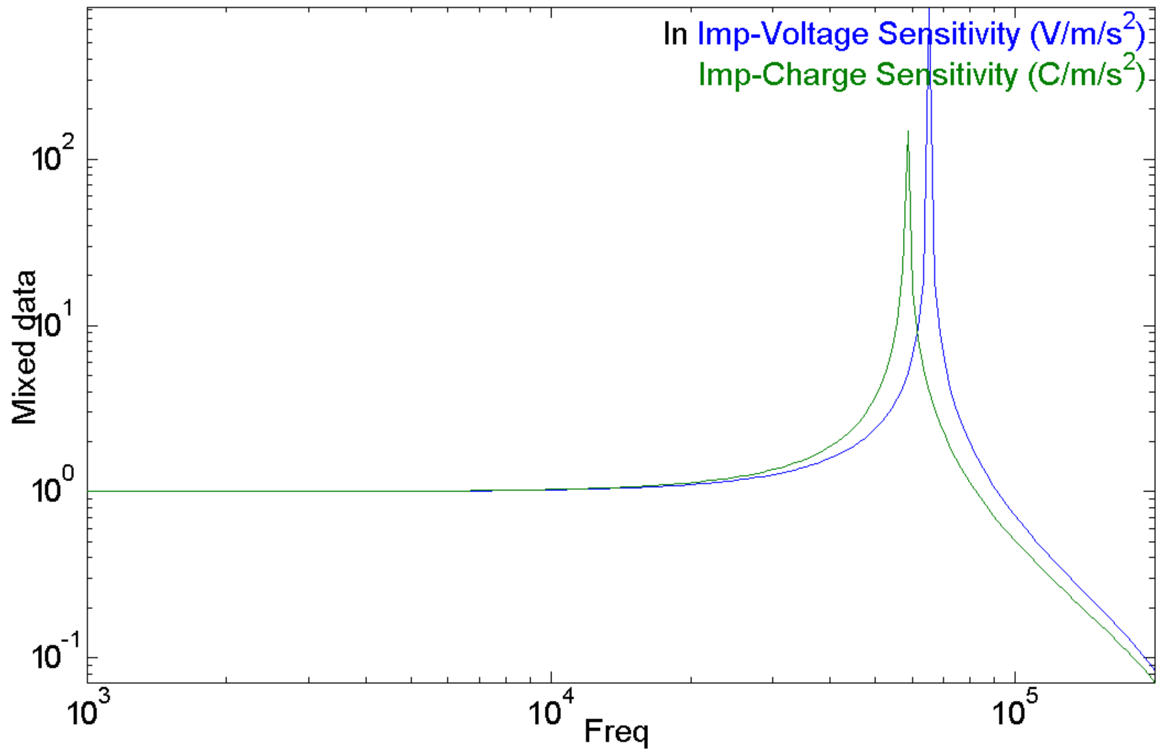
Main steps of an analysis

SDT supports piezoelectric constitutive laws for all 3D volume elements and composite shells. The main steps of an analysis are :

- define/import **mesh**.
- define piezoelectric **material properties**
- define **electrodes** through an MPC for volumes or the element property for shells.
- define electric boundary conditions, loading, and sensors
- compute the **response** using full order or reduced order models
- visualize the response in more detail.

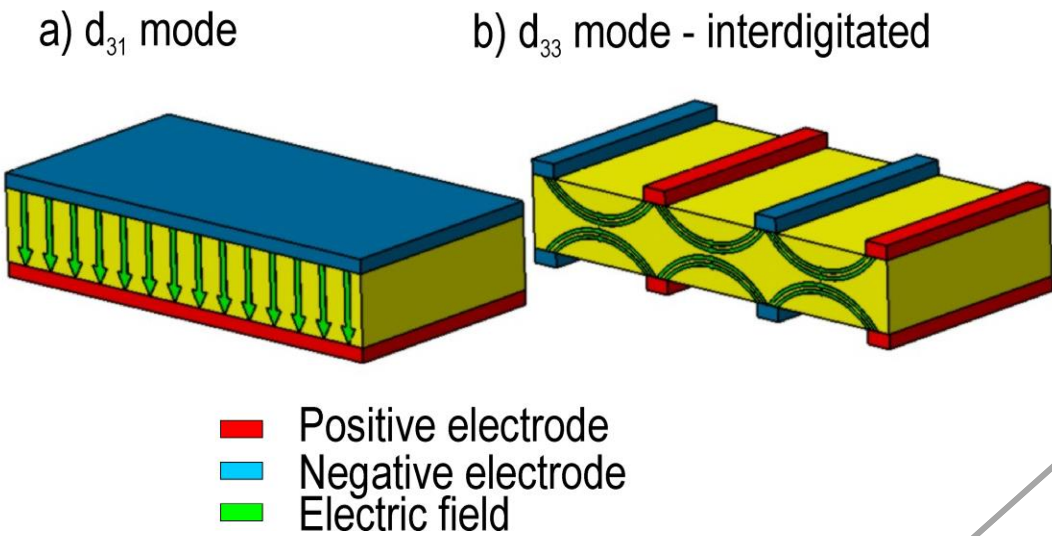
Piezo volumes and transfers: accelerometer example

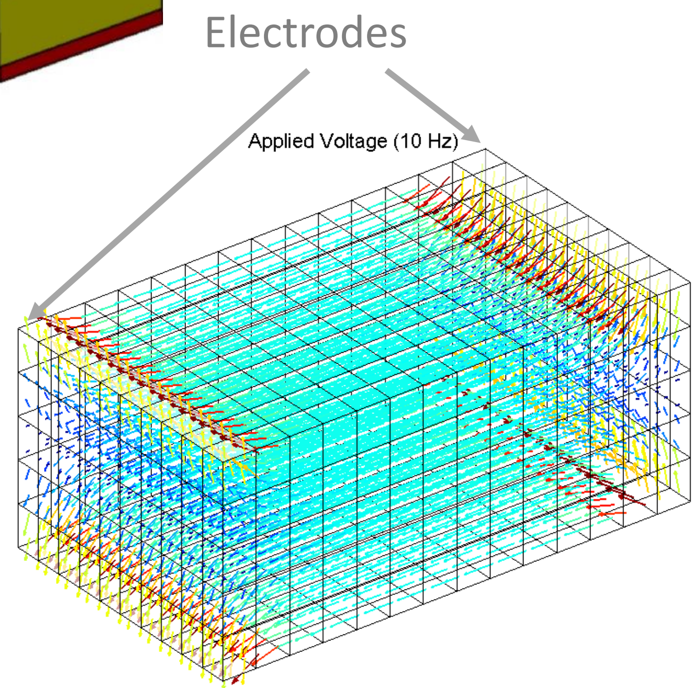




Computation of the sensitivity of the accelerometer to a base excitation.
Comparison of voltage vs charge sensitivity

Piezo volumes and advanced views : IDE example

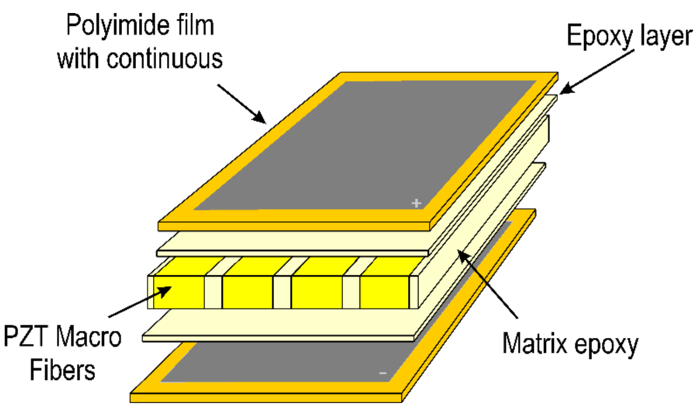


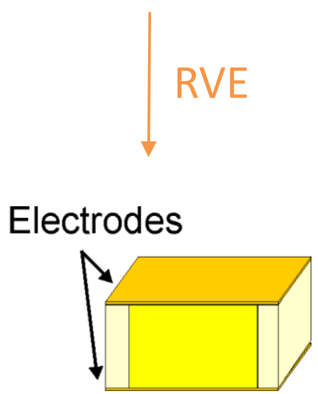


Visualisation of the curved electric field when using interdigitated electrodes

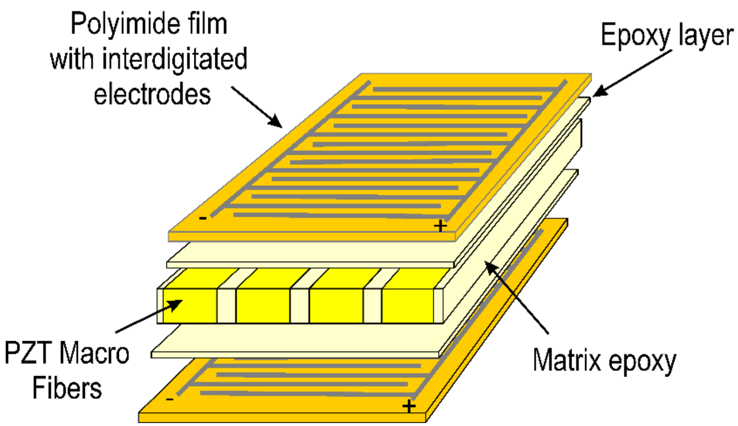
Piezo volumes : periodic homogenization of piezocomposite transducers

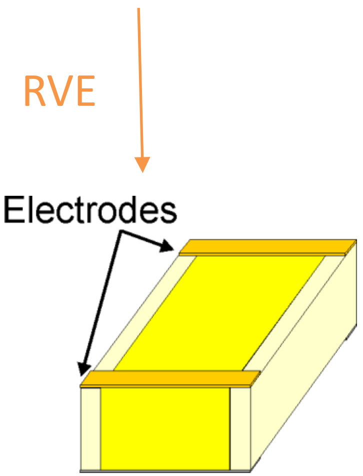
d31 P2-type MFC





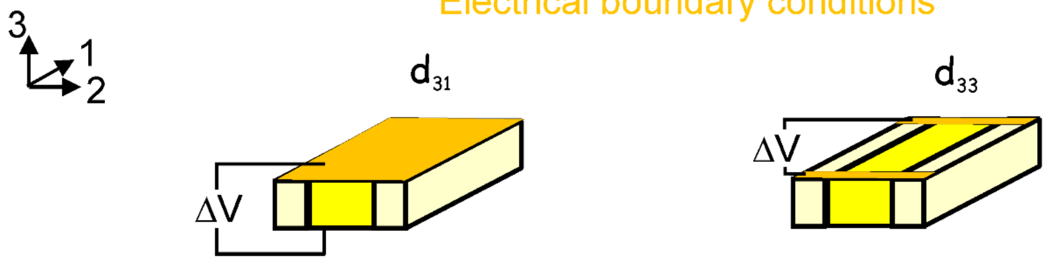
d33 P1-type MFC





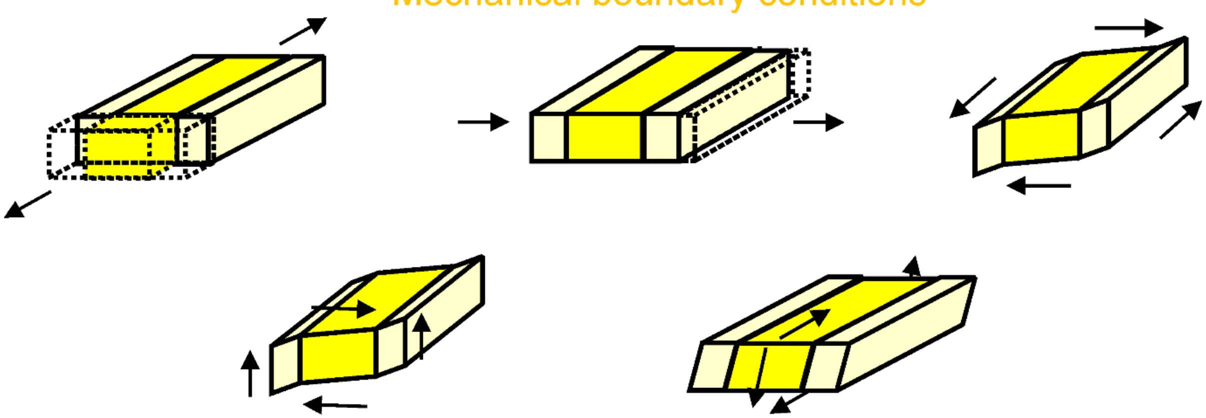
Piezo volumes : periodic homogenization of piezocomposite transducers

Electrical boundary conditions



All faces with the normal in the plane of the actuator blocked

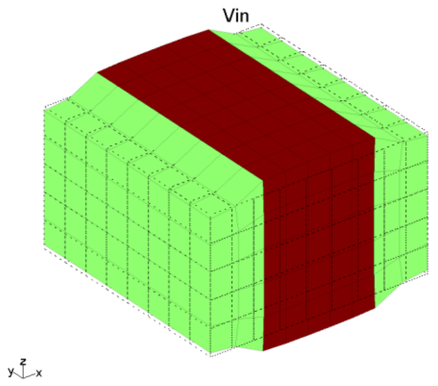
Mechanical boundary conditions

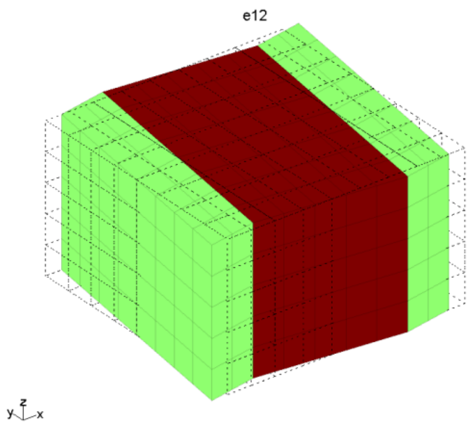


$\Delta V=0$

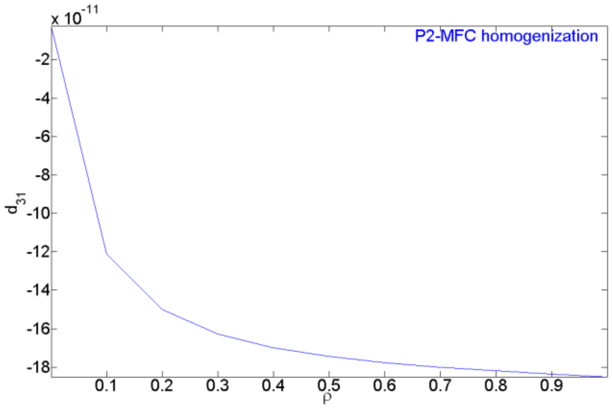
Piezo volumes : periodic homogenization of piezocomposite transducers

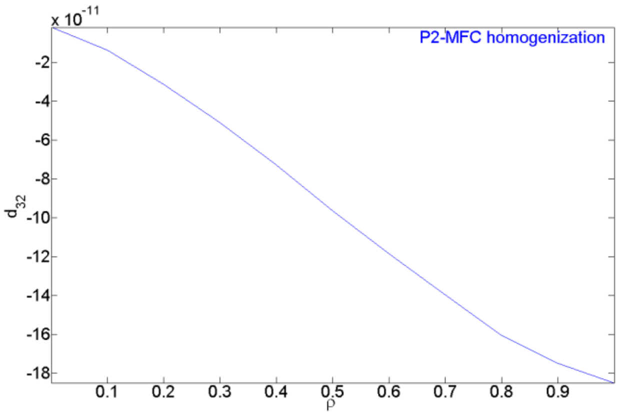
Computation of the six local problems using SDT : P2 MFC





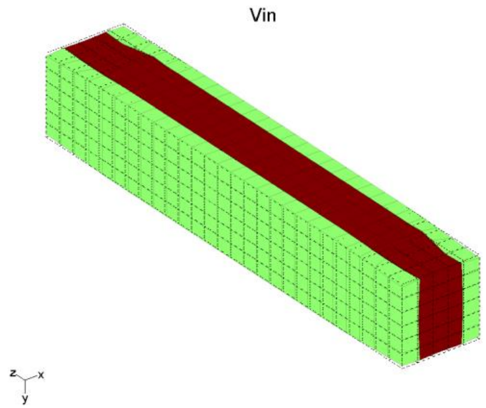
Post-processing to get the homogeneous properties as a function of the volume fraction of fibers ρ

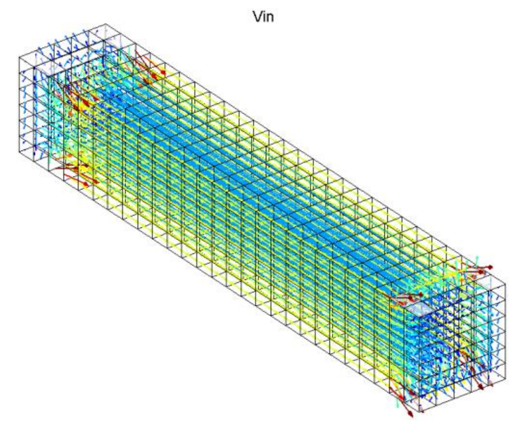




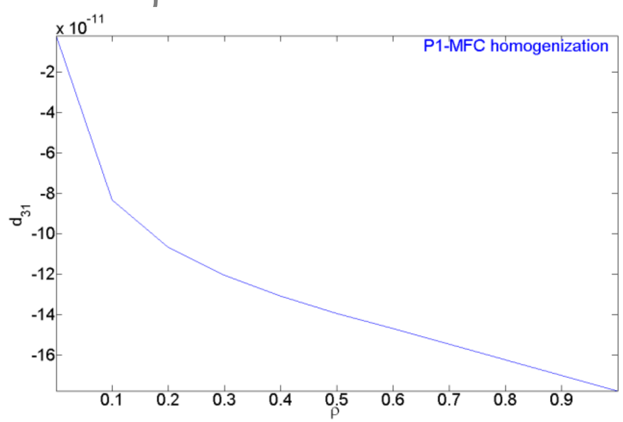
Piezo volumes : periodic homogenization of piezocomposite transducers

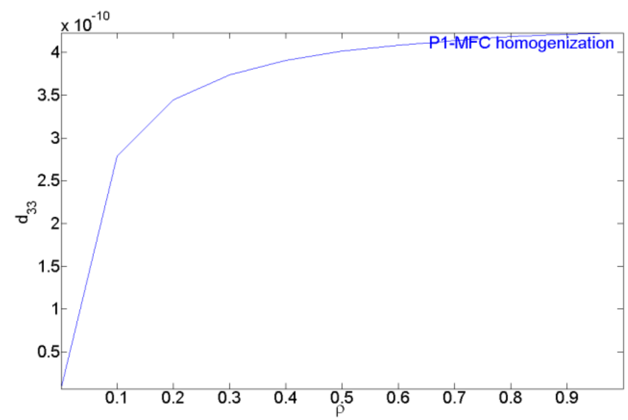
Computation of the six local problems using SDT : P1-MFC



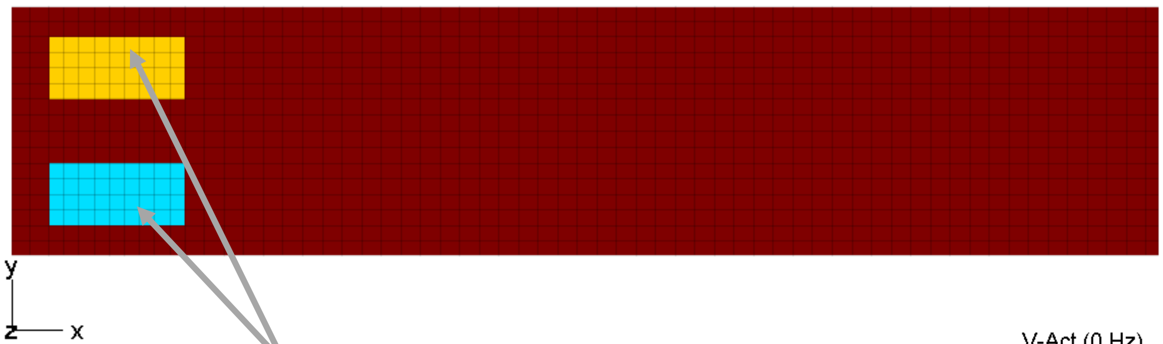


Post-processing to get the homogeneous properties as a function of the volume fraction of fibers ρ

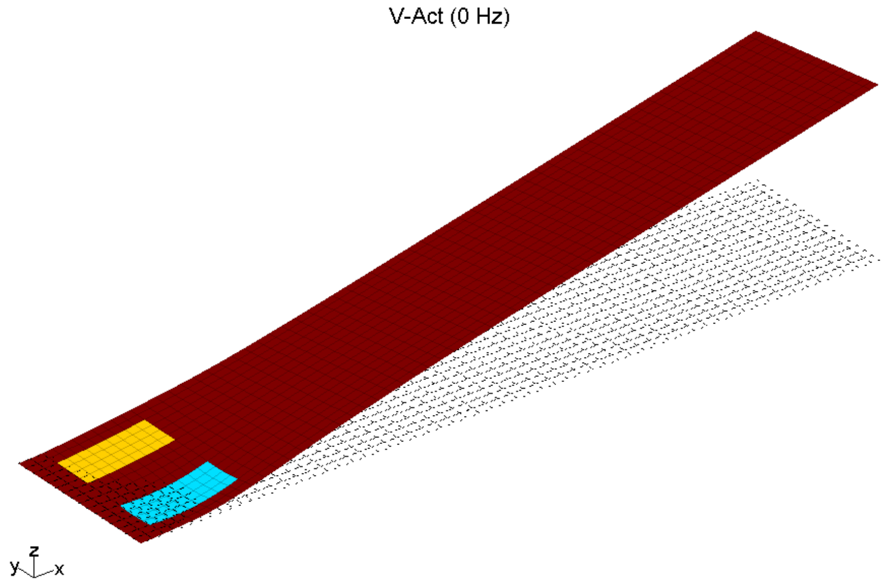




Piezo shells and transfers : plate with 4 piezoelectric patches

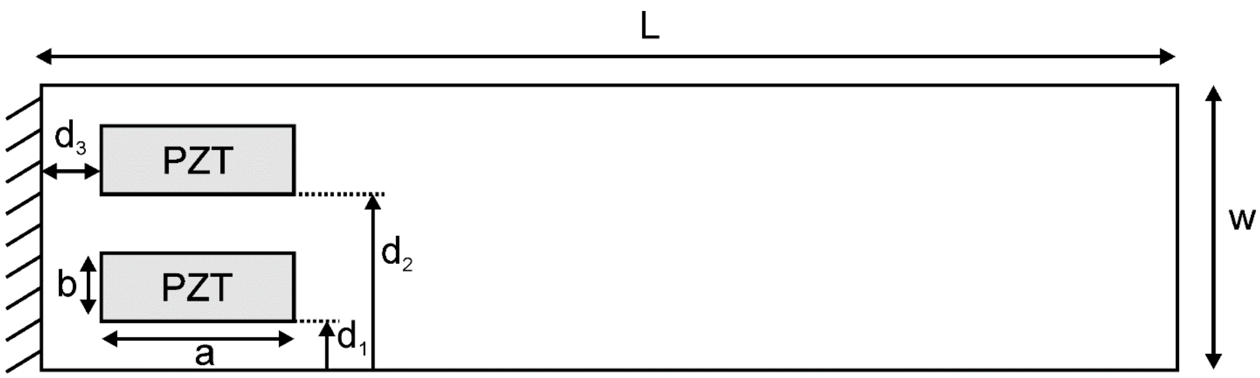


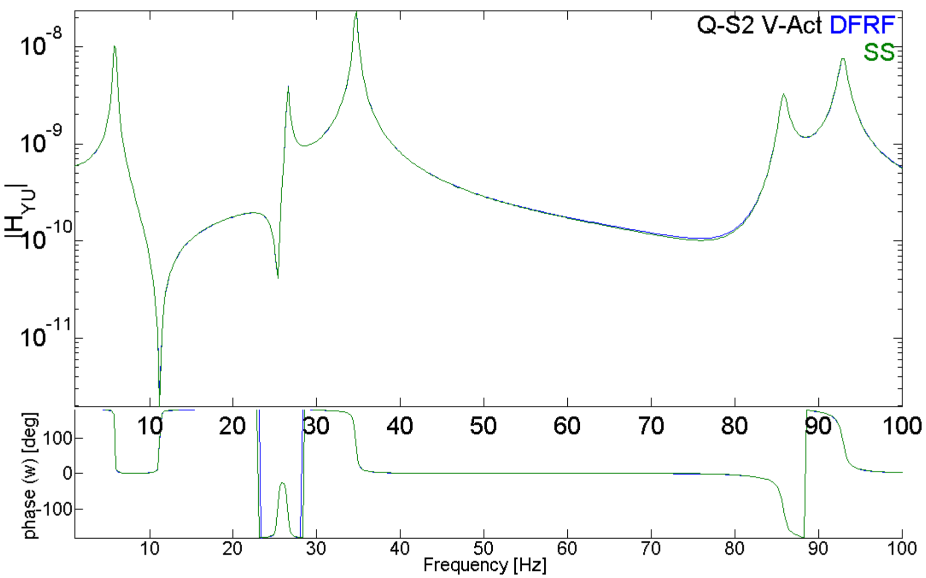
Piezoelectric patches
(two on each side)



Static response to a voltage applied to the blue patch

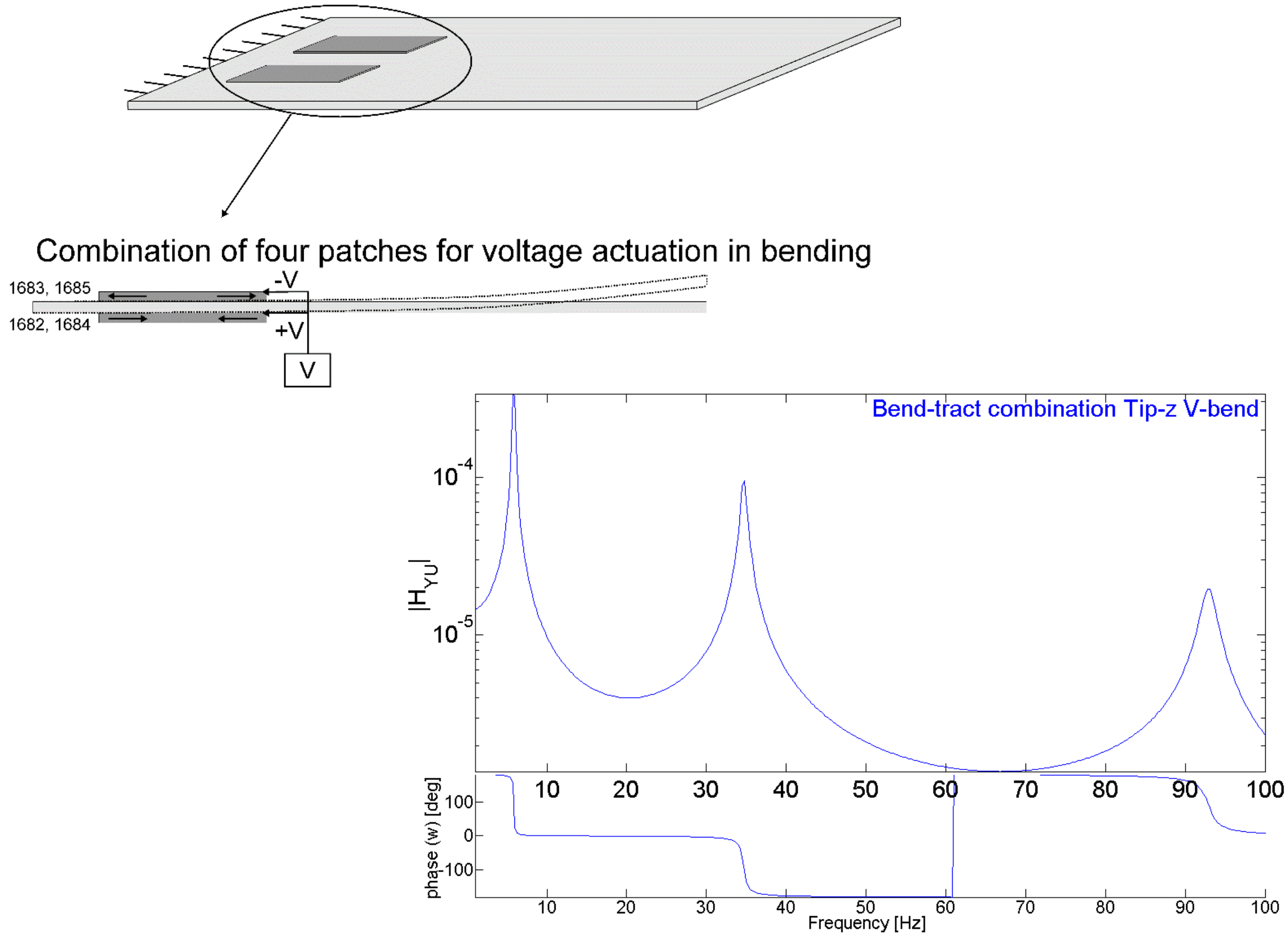
Piezo shells and transfers : plate with 4 piezoelectric patches





Transfer function between a voltage applied to one patch and the charge measured on another patch – comparison between full and reduced order (state-space) models.

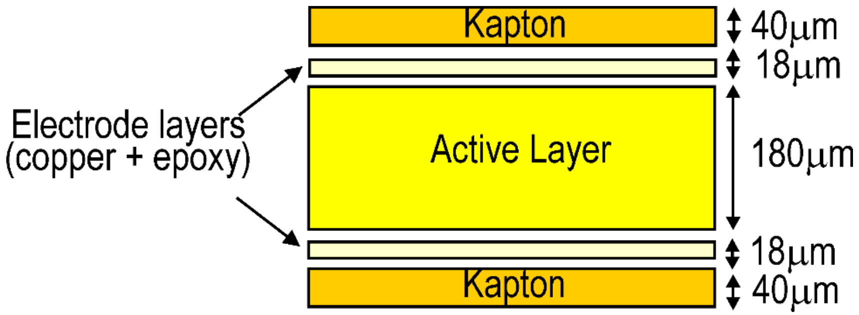
Piezo shells and transfers : plate with 4 piezoelectric patches



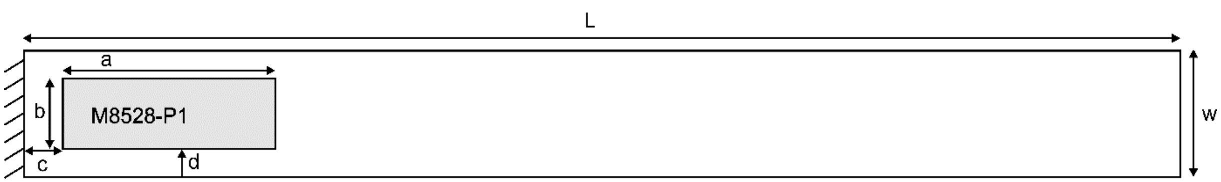
Combination of patches to induce pure bending of the plate. The FRF represents the tip displacement of the beam.

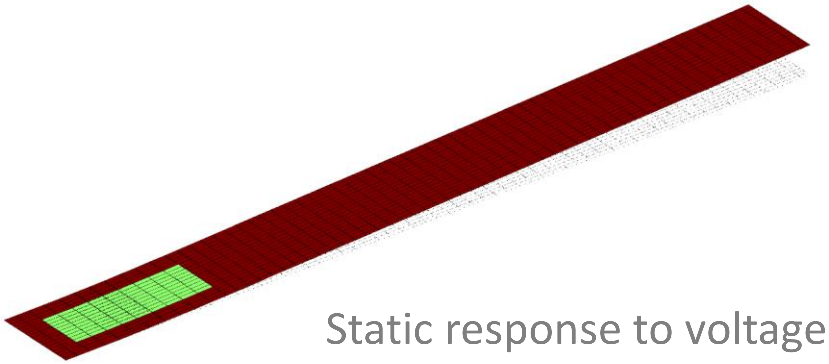
Integrating thin piezocomposite transducers in plate models

Multi-layer model



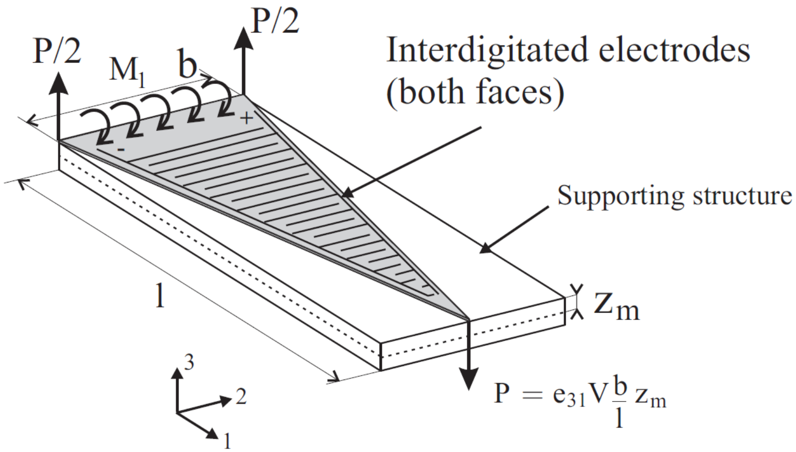
Active layer properties obtained from 3D piezo homogenization

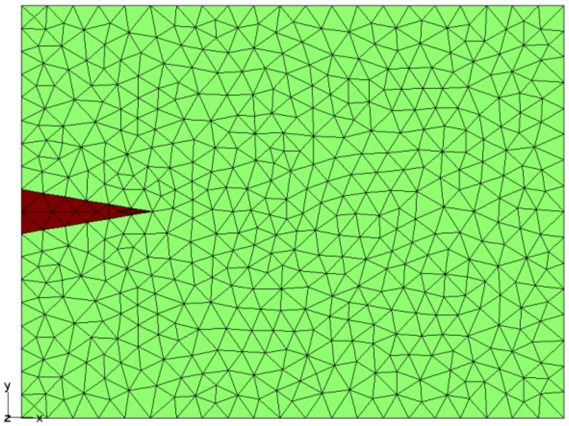


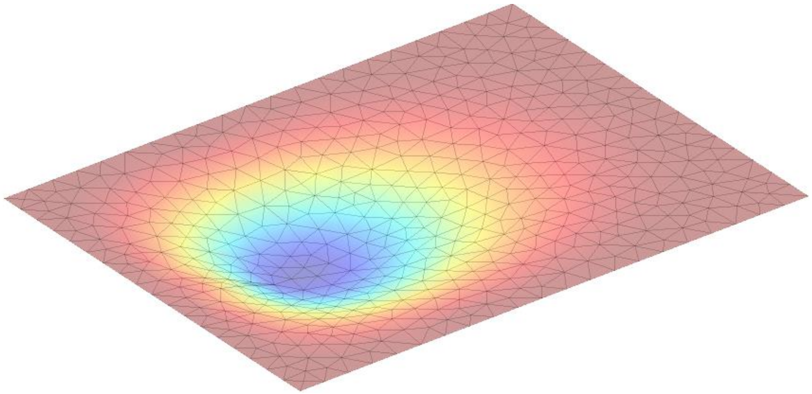


Static response to voltage applied on the MFC

Using shaped orthotropic piezoelectric transducers : triangular point load actuator

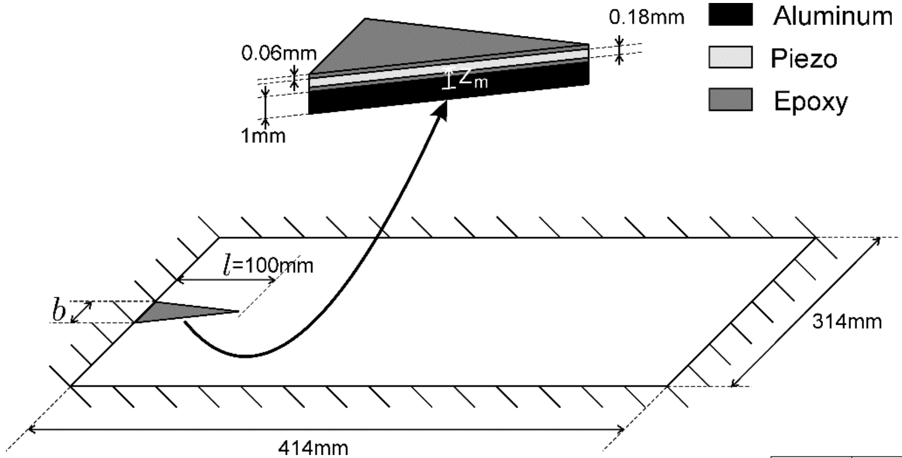


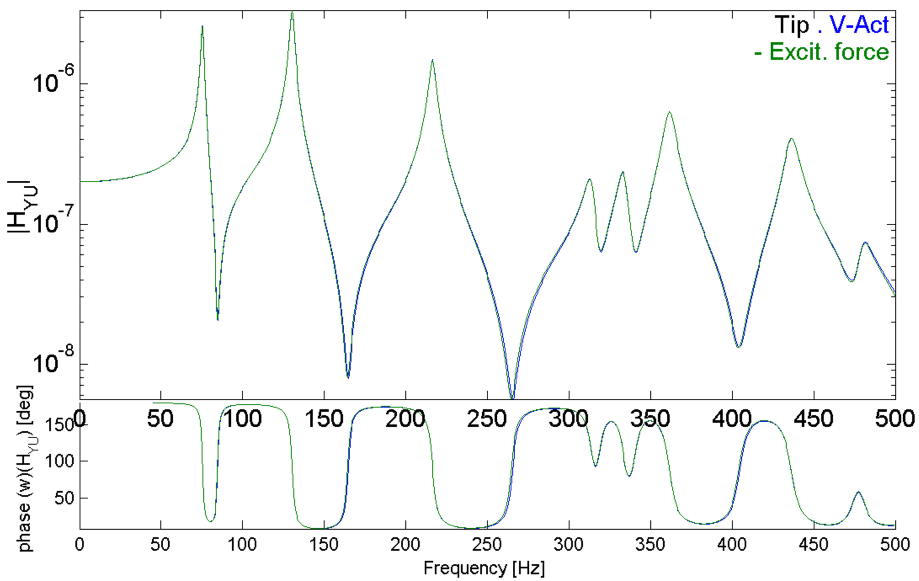




Static response

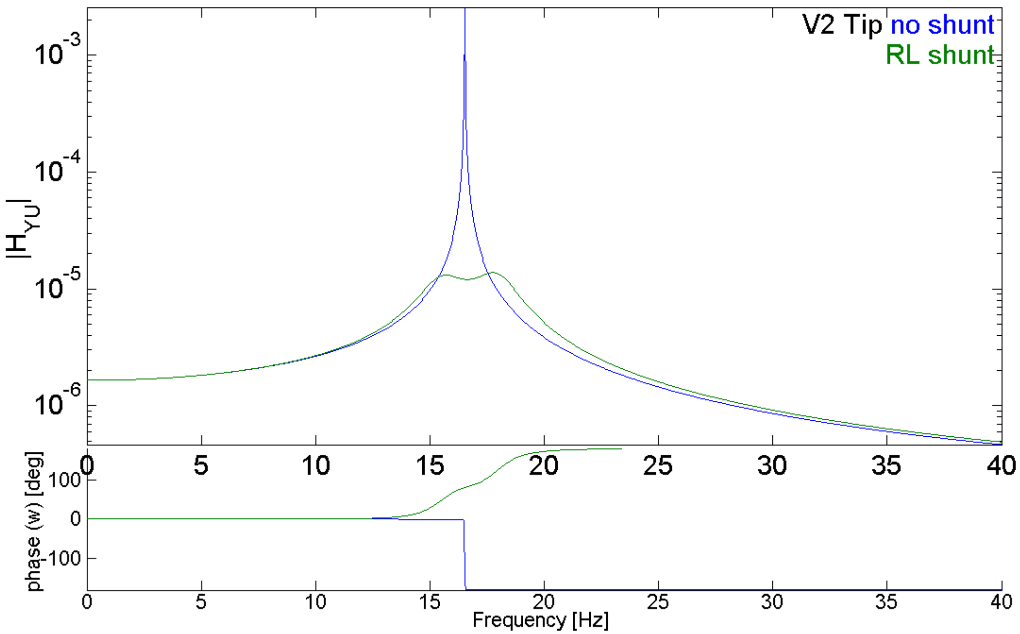
Using shaped orthotropic piezoelectric transducers : triangular point load actuator





Comparison between the collocated transfer function for the triangular actuator and for a real point load at the tip of the triangle

Vibration damping using a tuned resonant shunt circuit



Effect of an RL shunt tuned on the first mode shape

The piezoelectric module of SDT

- Is a **Matlab**-based tool that offers both **3D** and **shell elements** for the modelling of structures with piezoelectric materials
- Allows to **import meshes** from most commercial codes (Ansys, Nastran, Abaqus, Samcef) and treat complex problems with a **large number of degrees of freedom**
- Provides efficient tools for the definition of **piezo material properties** (existing database) and **electrodes** including combinations
- Enables to compute **static** and **dynamic** responses to voltage/charge actuation and define voltage/charge sensors using **full** and **reduced order** models
- Contains **advanced visualization tools** for easy pre and post-processing
- Allows to create reduced order **State-space** models from the full models for use with the **control toolbox** in Matlab

For further information contact

Arnaud Deraemaeker (aderaema@ulb.ac.be) or info@sdtools.com