Microstructure Simulation of Early Paper Forming Using Immersed Boundary Methods

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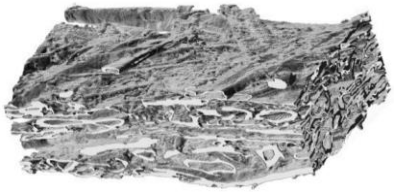
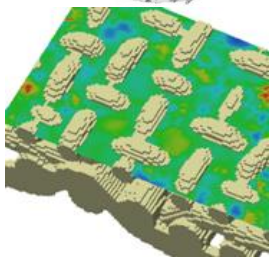
Innovative Simulation of Paper –

Micro-Structure Models for Papermaking and Paperboard Package Quality

ISOP

- Virtual fiber web model generation
- Development of software tools for simulation of papermaking and paperboard properties
- Measurements for calibration and validation
- Simulations of the effect of fiber properties, additives, forming fabrics and process conditions on paper forming and paper quality





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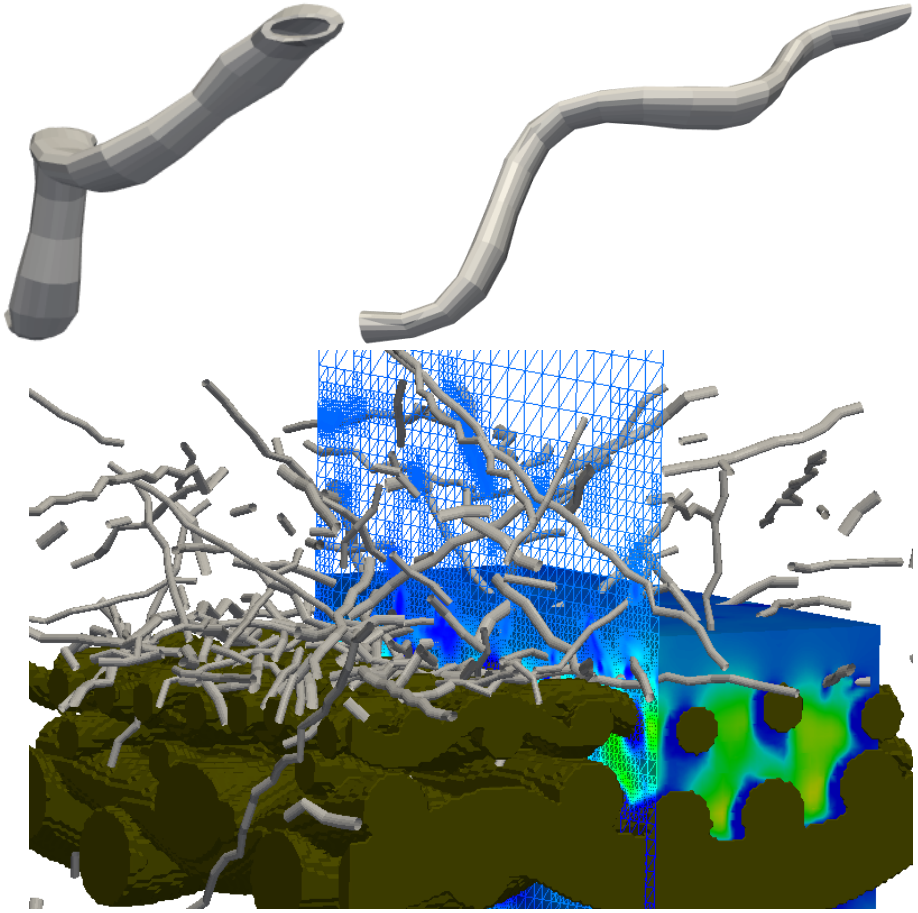
PROTECTS WHAT'S GOOD Tetra Pak

Paper forming

Goal: Simulation of buildup of a paper web on a virtual forming fabric

- The fibers are modeled as slender objects with elliptical cross section
- The fluid flow around the fibers is resolved with the hybrid immersed boundary method
- The fibers are modeled as Euler-Bernoulli beams
- The contacts are handled with a penalty method

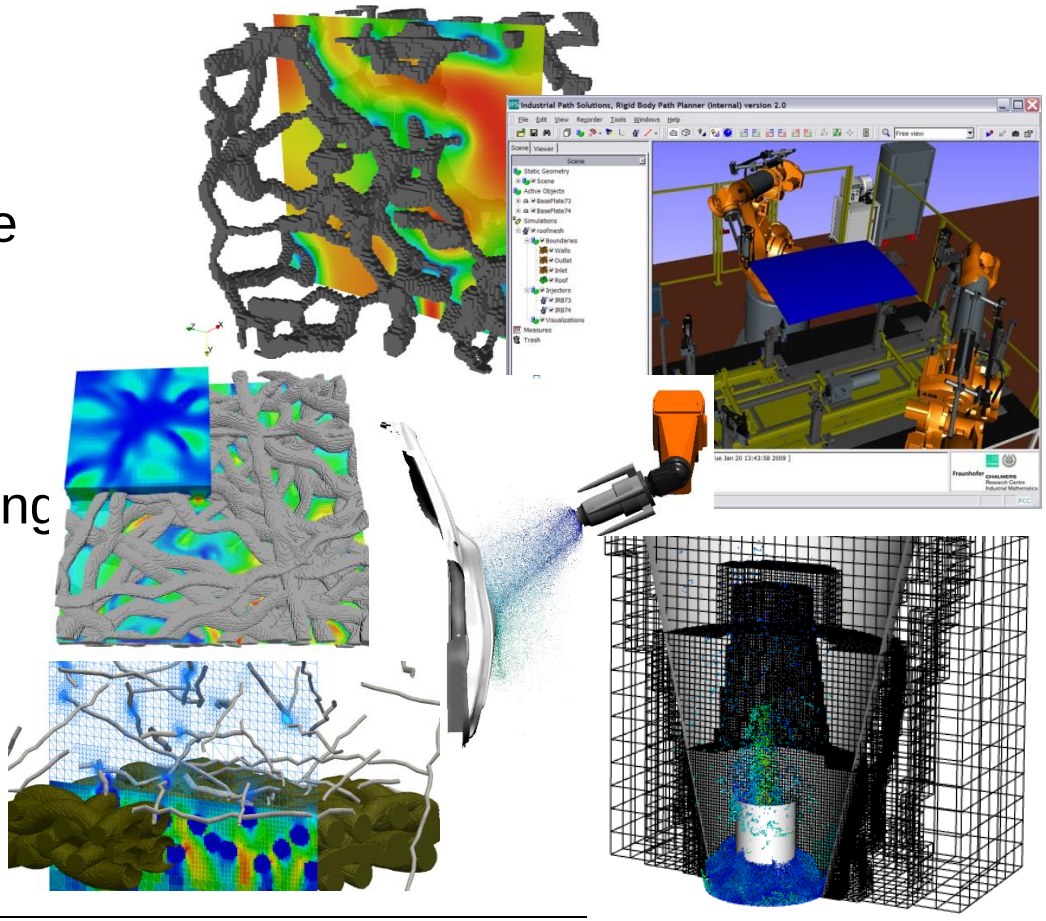


Mark et al: *Microstructure Simulation of Early Paper Forming Using Immersed Boundary Methods,* To appear in TAPPI Journal (2011)

– Immersed Boundary Octree Flow Solver

IBOFlow

- Fully dynamic refinement and coarsening of Cartesian octree grid
- Novel immersed boundary methods
- Arbitrary, moving and interacting bodies without re-meshing
- Particle and spray models
- Volume of fluids
- Heat transfer



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The Hybrid Immersed Boundary Method

- Models the presence of the bodies in the fluid by interior boundary conditions
  - Momentum equation: Implicit Immersed Boundary Condition
  - Continuity equation: Physical condition, zero mass flux over IB
- No boundary fitted volume grid requried
- Handles moving, interacting and deforming bodies efficiently

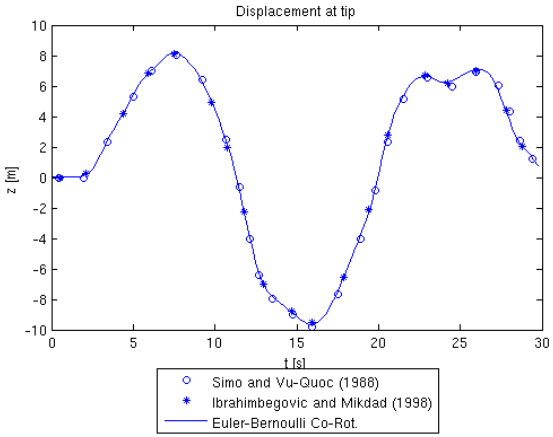
A. Mark, R. Rundqvist and F. Edelvik: *Comparison Between Different Immersed Boundary Conditions for Simulation of Complex Fluid Flows,* Fluid Dynamics and Materials Processing 7 (2011)

Fiber model

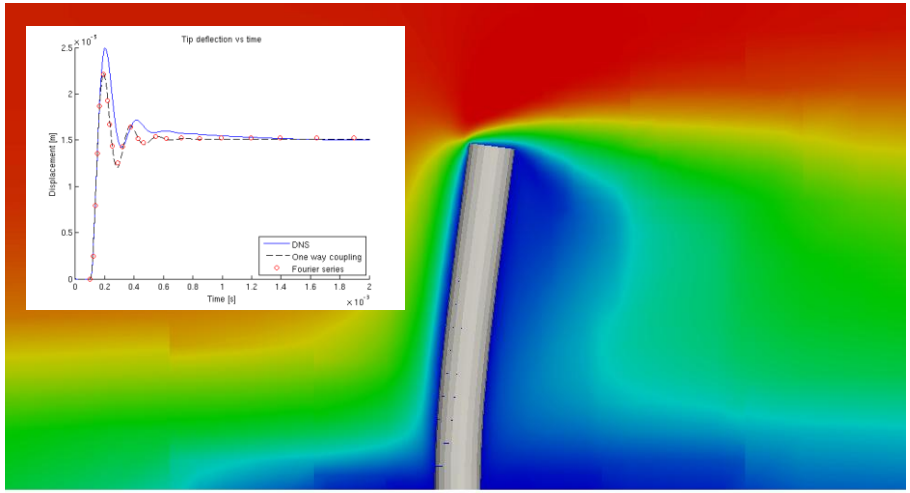
- Euler-Bernoulli beams in co-rotational formulation
  - A coordinate system follows every element
  - Geometric nonlinearity through CR-formulation
- Contacts are modeled with a penalty method
  - Elastic/inelastic collisions are accounted for by introducing the coefficient of restitution in the expression for the normal force
  - Friction is included with a regularization of Coulomb's law
  - Fiber-fiber contact as well as fiber-fabric contact can be handled

E. Svenning: *Development of a nonlinear Finite Element beam model for dynamic contact problems applied to paper forming.* MSc thesis, Chalmers University of Technology, Göteborg (2011)

Validation



- The fiber model and the contact model have been validated against cases described in the literature
  - Large amplitude oscillation of beams
  - Fiber-fiber and fiber-wall contact
- Fluid-structure interaction: comparison with drag correlation and Fourier series expansion of the Euler-Bernoulli beam equation



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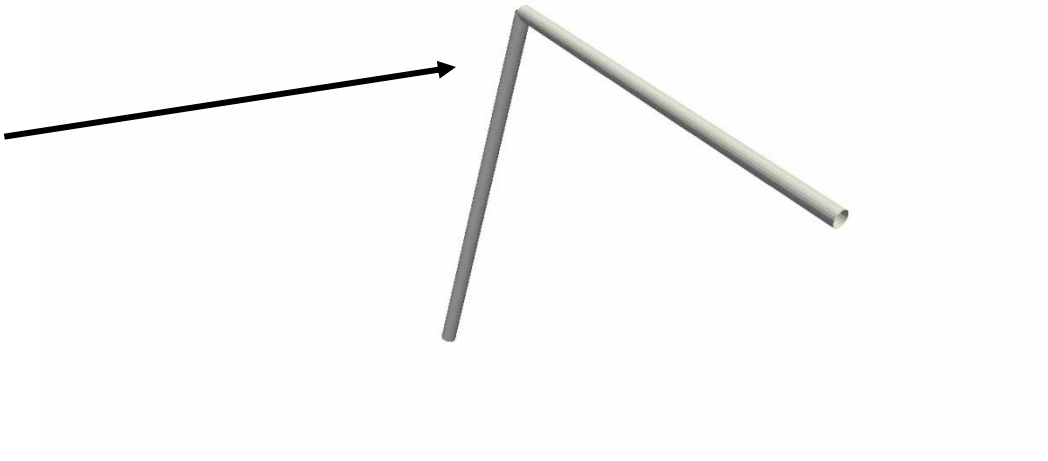
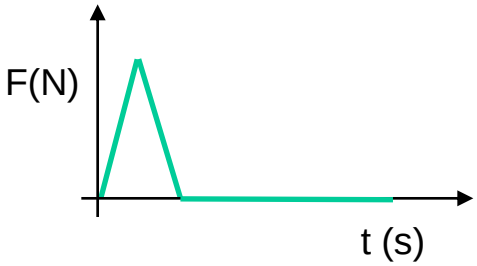
Dynamic elbow test case

Simo, J.C. and Vu-Quoc,L: *Comp. methods in app. mech. and eng.* 66 *(1988)* 125-161

- L-shaped beam
- Clamped at bottom
- Linear load on elbow the first 2 seconds

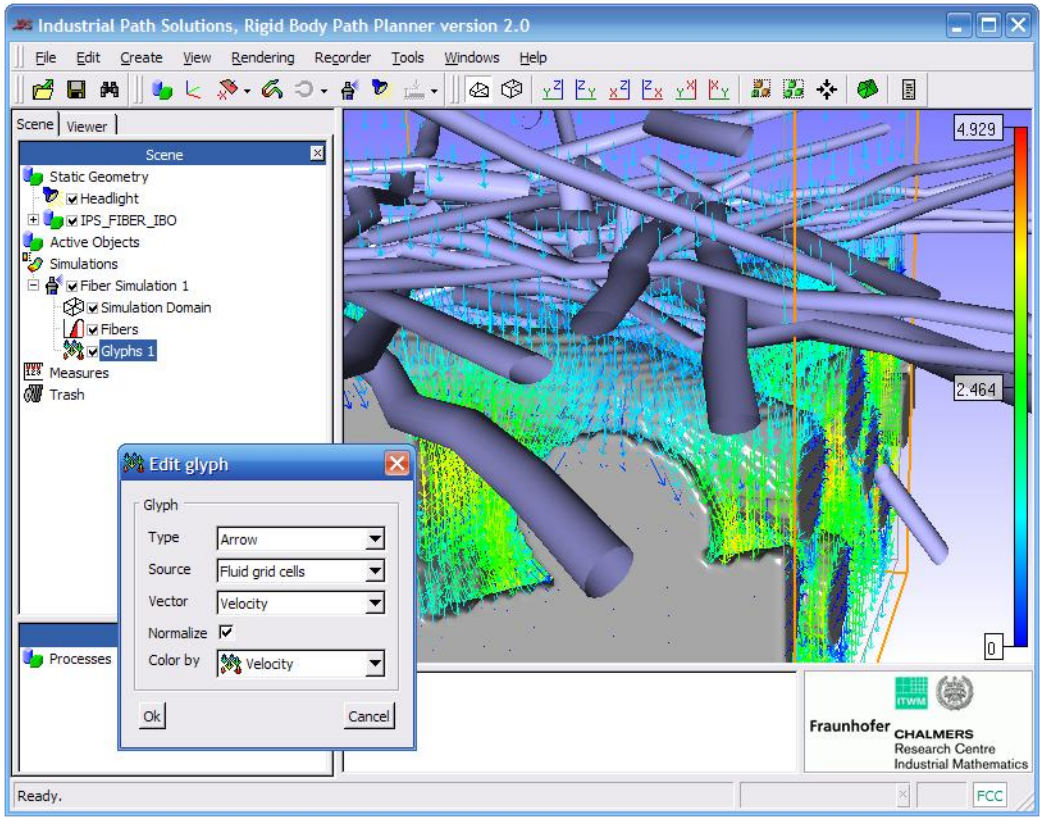




Property	GA_1	GA_2	EA	EI_1	EI_2	GJ	$A\rho$	$I\rho_{11}$	$I\rho_{22}$	$I\rho_{33}$
Value	1.0e6	1.0e6	1.0e6	1.0e3	1.0e3	1.0e3	1.0	10.0	10.0	20.0

Software tools

- Different forming fabrics and fiber properties
- Software tool with graphical user interface
- Modules tailored for different applications
- Pre- and postprocessing



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Initial simulation of paper forming

Conclusions

- Laydown simulations can be performed
- Submodels have been validated against results from the literature
- Comparison with test cases