This section contains a survey of poster presentations of actual PhD-projects within the Graduate School Engineering Mechanics. Furthermore, poster presentations are available through:

http://www.em.tue.nl
<table>
<thead>
<tr>
<th>Name</th>
<th>Uni</th>
<th>Poster title</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.Sc. D. Akcay Perdahcioğlu</td>
<td>UT</td>
<td>Design Optimization of Structures utilizing Dynamic Substructuring and Artificial Intelligence Techniques</td>
</tr>
<tr>
<td>Ir. I. Akkerman</td>
<td>TUD</td>
<td>Adaptive residual-based multiscale modeling</td>
</tr>
<tr>
<td>Dr. A. Andreykiv</td>
<td>TUD</td>
<td>Simulation of electrostatic-structural coupling using fictitious domain and level set methods</td>
</tr>
<tr>
<td>M.Sc. W. Assaad</td>
<td>UT</td>
<td>Isothermal simulation of an aluminum extrusion process with a multi-hole die</td>
</tr>
<tr>
<td>Ir. A. Balmachnov</td>
<td>TU/e</td>
<td>Modeling martensitic transformation in austenitic steel</td>
</tr>
<tr>
<td>Ir. R.A. van den Berg</td>
<td>TU/e</td>
<td>Convergent Anti-Windup Controller Design: Experimental Results</td>
</tr>
<tr>
<td>Ir. C.T. Bolsman</td>
<td>TUD</td>
<td>Development of an Artificial Miniature Flying Device</td>
</tr>
<tr>
<td>Ir. R. Bosman</td>
<td>UT</td>
<td>Microscopic Mild Wear in the Boundary Lubrication regime</td>
</tr>
<tr>
<td>M.Sc. A. Boustheen</td>
<td>TU/e</td>
<td>Massively Parallel Microsystems through Precision Replication</td>
</tr>
<tr>
<td>Ir. I.A. Burchitz</td>
<td>UT</td>
<td>Accurate simulation of springback using adaptive integration</td>
</tr>
<tr>
<td>Ir. R.J.H. Cloots</td>
<td>TU/e</td>
<td>Influences of the heterogeneities of the cerebral cortex for traumatic brain injury</td>
</tr>
<tr>
<td>Ir. E.W.C. Coenen</td>
<td>TU/e</td>
<td>Forming the limits of Damage Predictions: Microstructural modeling</td>
</tr>
<tr>
<td>Ir. E.W.C. Coenen</td>
<td>TU/e</td>
<td>Multi-scale computational homogenization of structured thin sheets</td>
</tr>
<tr>
<td>Ir. I. Cracauer</td>
<td>UT</td>
<td>Influence of wear on lubricated systems. Experimental work</td>
</tr>
<tr>
<td>Ir. N.P. van Dijk</td>
<td>TUD</td>
<td>Multi-field topology optimization; strong coupling at the interface</td>
</tr>
<tr>
<td>Ir. W. Dijkstra</td>
<td>TU/e</td>
<td>Simulating the blowing of glass bottles using the boundary element method</td>
</tr>
<tr>
<td>M.Sc. E. Dikmen</td>
<td>UT</td>
<td>Advanced Modeling of High Speed Micro Rotodynamics</td>
</tr>
<tr>
<td>M.Sc. M. Erinç</td>
<td>TU/e</td>
<td>Predicting solder reliability by microstructural modeling</td>
</tr>
<tr>
<td>Ir. C.F. Fagiano</td>
<td>TUD</td>
<td>Computational modelling of tow-placed composite laminates using layerwise theories</td>
</tr>
<tr>
<td>Ir. J.A.W.M. Groot</td>
<td>TU/e</td>
<td>Inverse Modelling of Glass Blow Forming Processes</td>
</tr>
<tr>
<td>Ir. W.J.B. Grouve</td>
<td>UT</td>
<td>Optimising the consolidation of thermoplastic composite laminates</td>
</tr>
<tr>
<td>Ir. S.D.A. Hannot</td>
<td>TUD</td>
<td>Determining Pull-In Curves with Electromechanical FEM Models</td>
</tr>
<tr>
<td>Dipl. Ing. T.S. Hille</td>
<td>TUD</td>
<td>Cohesive crack modeling based on the partition of unity method for thermal barrier coatings (TBCs)</td>
</tr>
<tr>
<td>Ir. W. Hoitinga</td>
<td>TUD</td>
<td>From particles to continuum: An FE method for the Boltzmann equation</td>
</tr>
<tr>
<td>Ing. M. Hrapko</td>
<td>TU/e</td>
<td>The effect of different constitutive models for brain tissue in a numerical head model</td>
</tr>
<tr>
<td>M.Sc. E. Ivanov</td>
<td>TU/e</td>
<td>Scheduling and resource management in MRI examinations</td>
</tr>
<tr>
<td>M.Sc. H.R. Javani Joni</td>
<td>TU/e</td>
<td>Three-dimensional computational modelling of ductile damage and fracture</td>
</tr>
<tr>
<td>Ir. G.A. Kakuba</td>
<td>TU/e</td>
<td>Convergence Analysis of LBC for BEM</td>
</tr>
<tr>
<td>Ir. W.R. Kampinga</td>
<td>UT</td>
<td>Modeling a hearing aid loudspeaker</td>
</tr>
<tr>
<td>M.Sc. Y.P. Karade</td>
<td>TU/e</td>
<td>Stress relaxation of locally cross-linked and stretched polymer substrates on nanometer scales</td>
</tr>
<tr>
<td>M.Sc. M. Kolluri</td>
<td>TU/e</td>
<td>Characterization of interface delamination in integrated microsystems</td>
</tr>
<tr>
<td>Ir. A.J. Koopman</td>
<td>UT</td>
<td>Material modelling based on comparison between simulations and experiments</td>
</tr>
<tr>
<td>Ir. F. Kraaijeveld</td>
<td>TU/e</td>
<td>Osmoporomechanical coupling in cracks</td>
</tr>
<tr>
<td>M.Sc. S. Kurukuri</td>
<td>UT</td>
<td>Simulation of warm forming of Aluminum sheet: Physically based constitutive models</td>
</tr>
<tr>
<td>Ir. G. Lau</td>
<td>TUD</td>
<td>Powerful Thermoelastic Actuation with Expoxy</td>
</tr>
<tr>
<td>Ir. G. van der Linde</td>
<td>UT</td>
<td>Galling in Deep Drawing</td>
</tr>
<tr>
<td>M.Sc. O. Lloberas Valls</td>
<td>TUD</td>
<td>A two-scale computational framework for softening materials</td>
</tr>
<tr>
<td>Ir. J.M. Lopez de la Cruz</td>
<td>TUD</td>
<td>Prediction of corrosion clustering through spatial statistics</td>
</tr>
<tr>
<td>Ir. N.J. Mallon</td>
<td>TU/e</td>
<td>Dynamic stability of a base excited thin cylindrical shell with top mass</td>
</tr>
<tr>
<td>Ir. F.P. van der Meer</td>
<td>TUD</td>
<td>Softening plasticity for orthotropic materials</td>
</tr>
<tr>
<td>Ir. R.M.C. Mestrom</td>
<td>TU/e</td>
<td>Phase feedback for nonlinear MEMS resonators</td>
</tr>
<tr>
<td>Ir. M.J.J. Nijhof</td>
<td>UT</td>
<td>An acoustic finite element including viscothermal effects</td>
</tr>
<tr>
<td>Name</td>
<td>Institution</td>
<td>Title</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>M.Sc. M. Nikbakht</td>
<td>TUD</td>
<td>Automated modelling of discontinuities</td>
</tr>
<tr>
<td>M.Sc. K.B. Oelgaard</td>
<td>TUD</td>
<td>Automated modelling for discontinuous Galerkin methods</td>
</tr>
<tr>
<td>M.Sc. P. Owczarek</td>
<td>UT</td>
<td>Oil-free piston compressors</td>
</tr>
<tr>
<td>M.Sc. M. Ozbek</td>
<td>TUD</td>
<td>Optical Monitoring of Wind Turbine Dynamics</td>
</tr>
<tr>
<td>Ir. I. Özdemir</td>
<td>TU/e</td>
<td>Computational Homogenization for Thermomechanical Analysis of heterogeneous Solids</td>
</tr>
<tr>
<td>Ir. V.K. Pahlwani</td>
<td>TU/e</td>
<td>Bio-inspired Parallel Assembly of Mesoscale Components</td>
</tr>
<tr>
<td>M.Sc. E.S. Perdahcioğlu</td>
<td>UT</td>
<td>Constitutive modeling of metastable austenitic stainless steel</td>
</tr>
<tr>
<td>Ir. G.W. van der Poel</td>
<td>UT</td>
<td>Design of a smart mount for vibration isolation in precision equipment</td>
</tr>
<tr>
<td>M.Sc. R.I. Popovici</td>
<td>UT</td>
<td>Slippery Tracks: Wheel - Rail Contact</td>
</tr>
<tr>
<td>Dipl.-Ing. F.K.F. Radtke</td>
<td>TUD</td>
<td>A Computational Approach to Model Fibre Reinforced Concrete</td>
</tr>
<tr>
<td>M.Sc. T. Rahman</td>
<td>TUD</td>
<td>Finite Element Based Reduced Complexity Analysis of Shells of Revolution</td>
</tr>
<tr>
<td>Ir. M. van Riel</td>
<td>UT</td>
<td>Strain Path Sensitivity of Mild Steel in Experiment and Model</td>
</tr>
<tr>
<td>Dr. A. Roy</td>
<td>TU/e</td>
<td>On the relevance of discreteness in plasticity</td>
</tr>
<tr>
<td>M.Sc. M. Samimi</td>
<td>TU/e</td>
<td>Towards enrichment of cohesive zone models for numerical simulation of interfacial delamination</td>
</tr>
<tr>
<td>M.Sc. M.K. Saraswat</td>
<td>TUD</td>
<td>A Qualitative study of the Void formation using Ultrasounds during the VARTM process</td>
</tr>
<tr>
<td>Ir. J.H. Schutte</td>
<td>UT</td>
<td>Tyre/Road Noise</td>
</tr>
<tr>
<td>M.Sc. X. Shan</td>
<td>TUD</td>
<td>Thermal effects on two-phase flow in porous media</td>
</tr>
<tr>
<td>M.Sc. J. Shi</td>
<td>TUD</td>
<td>The competition between solid-state phase transformations and plastic deformation: discrete interfaces and discrete dislocations</td>
</tr>
<tr>
<td>Ir. P.J. Sloetjes</td>
<td>UT</td>
<td>Adaptive rotor systems with piezoelectric actuation</td>
</tr>
<tr>
<td>Ir. Q.H.C. Snippe</td>
<td>UT</td>
<td>Material modeling for the benefit of superplastic forming simulations</td>
</tr>
<tr>
<td>Drs. A. Sridhar</td>
<td>UT</td>
<td>Adhesion Characterisation in Inkjet Printing</td>
</tr>
<tr>
<td>Ir. R. van der Steen</td>
<td>TU/e</td>
<td>FEM Tyre Modeling</td>
</tr>
<tr>
<td>Ir. A.M. Steenhoek</td>
<td>TUD</td>
<td>Model Reduction Techniques for fast reanalysis in MEMS optimization</td>
</tr>
<tr>
<td>Ir. D.R. Suarez Venegas</td>
<td>TUD</td>
<td>Estimation of Micromotions Between a Cementless Orthopaedic Implant and Bone</td>
</tr>
<tr>
<td>M.Sc. N.J. Suman Nakka</td>
<td>TUD</td>
<td>Effect of small changes in initial adhesive resin chemistry on the viscoelasticity of its cured product</td>
</tr>
<tr>
<td>Ir. C.C. Tasan</td>
<td>TU/e</td>
<td>Uniaxial Tension vs Biaxial Tension: A Comparison of Microvoid Evolution</td>
</tr>
<tr>
<td>Dr. B.K. Thakkar</td>
<td>TU/e</td>
<td>Understanding Degradation in Paper</td>
</tr>
<tr>
<td>Ir. D.D. Tjahjanto</td>
<td>TUD</td>
<td>Micromechanical modeling and simulations of thermo-mechanical behavior of multiphase TRIP-assisted steels</td>
</tr>
<tr>
<td>Ir. S. Tosserams</td>
<td>TU/e</td>
<td>Distributed optimization for microsystem design</td>
</tr>
<tr>
<td>Ir. C.L. Valentin</td>
<td>TUD</td>
<td>The HYDRA control study</td>
</tr>
<tr>
<td>Ir. A. Verhoeven</td>
<td>TU/e</td>
<td>Automatic partitioning and multirateing applied to IC transient analysis</td>
</tr>
<tr>
<td>M.Sc. C.V. Verhoosel</td>
<td>TUD</td>
<td>Multi-scale modelling of fracture in piezoelectric ceramics</td>
</tr>
<tr>
<td>Ir. H.A. Visser</td>
<td>UT</td>
<td>A new engineering approach to predict the long-term hydrostatic strength of uPVC pipes</td>
</tr>
<tr>
<td>Ing. E.G. de Vries</td>
<td>UT</td>
<td>Friction at Cryogenic Temperatures</td>
</tr>
<tr>
<td>Ir. J.W. Wind</td>
<td>UT</td>
<td>Vibration Measurements using Sound</td>
</tr>
<tr>
<td>Ir. A.J. de Wit</td>
<td>TUD</td>
<td>Multi-level Optimization of Composite Materials</td>
</tr>
<tr>
<td>M.Sc. T. Yalcinkaya</td>
<td>TU/e</td>
<td>Strain Path Dependency in BCC Crystals</td>
</tr>
<tr>
<td>Ir. K.G. van der Zee</td>
<td>TUD</td>
<td>Goal-oriented adaptivity for steady fluid-structure interaction</td>
</tr>
<tr>
<td>Ir. G.J. van Zwieten</td>
<td>TUD</td>
<td>Quantitative fault discontinuity modeling using the Partition of Unity Method</td>
</tr>
</tbody>
</table>
Design Optimization of Structures utilizing Dynamic Substructuring and Artificial Intelligence Techniques

D. Akçay Perdahcıoğlu, P.J.M. van der Hoogt and A. de Boer
Institute of Mechanics, Processes and Control – Twente
Chair of Structural Dynamics and Acoustics, University of Twente
P.O. Box 217, 7500 AE Enschede, The Netherlands
phone +31-(0)53-4895618, email d.akcay@utwente.nl

Introduction
The well known property of resonance is causing large displacements which indicates large strains and large stresses in mechanical systems. This may lead to the failure of the structure. Resonance conditions can only be tackled by changing the design of the structure.

Objective
Development of an efficient design optimization strategy for large scale structural dynamics problems.

Strategy, Application & Results

Strategy: The optimization strategy is illustrated in Fig. 1. In the strategy, utilized abbreviations stand for: Design of Computer Experiments (DOCE), Component Mode Synthesis (CMS), Neural Networks (NN), Genetic Algorithms (GA), Sequential Quadratic Programming (SQP).

Application: To demonstrate the strategy, the first natural frequency of the plate (see Fig. 2) is minimized under the constraint of keeping the total mass constant. The plate is clamped at the boundaries. The design parameters are only located in the second component which are the thickness of the plates, the width and the thickness of the ribs and the distance between the ribs. The CMS technique based on Craig-Bampton method is utilized for coupling the first component with the varying designs of the second component and obtaining a structural response for the training set (see Fig. 1).

Results: The first natural frequency is reduced from 357.89 Hz. to 71.61 Hz. by the modification of the plate thicknesses and the thickness and the width of the first rib in the second component (see Fig. 3).

Figure 1: Design Optimization Strategy

Figure 2: Application

Figure 3: Results
Adaptive residual-based multiscale modeling

I. Akkerman

Delft University of Technology, Faculty of Aerospace Engineering
Engineering Mechanics, PO Box 5058, 2600 GB Delft, The Netherlands
+31 (0)15 278 2070, I.Akkerman@tudelft.nl, www.lr.tudelft.nl/em

Introduction
Residual based multiscale modeling and the variational Germano identity are combined. Ultimate goal is to use this combination for Large-eddy simulation (LES) of turbulent flow.

Residual-based multiscale modeling

Start with the general variational statement:

\[ \text{Find } U \in \mathcal{V}, \text{ such that } \forall W \in \mathcal{V}, \]
\[ B(W, U) = F(W) \]

Discretizing introduces the following decomposition:

\[ U = U^h + U', \quad W = W^h + W', \quad \mathcal{V} = \mathcal{V}^h + \mathcal{V}' \]

Yielding the equivalent variational statements:

\[ \text{Find } U^h \in \mathcal{V}^h \text{ and } U' \in \mathcal{V}', \text{ such that,} \]
\[ B(W^h, U^h + U') = F(W^h) \quad \forall W^h \in \mathcal{V}^h \]
\[ B(W', U^h + U') = F(W') \quad \forall W' \in \mathcal{V}' \]

Approximate \( U' \) based on \( W' \) equation:

\[ U' = -\tau R(U^h) \]

\[ R(U^h) = \text{residual of the underlying strong form} \]
\[ \tau = \tau(h, c) = \text{coefficient matrix} \]

Substitute \( U' \) in \( W' \) equation and rearrange:

\[ \text{Find } U^h \in \mathcal{V}^h, \text{ such that } \forall W^h \in \mathcal{V}^h, \]
\[ B(W^h, U^h) + M(W^h, U^h; h, c) = F(W^h) \]

Variational Germano Identity

Project solution \( U^h \) on a coarse mesh \( U^H \in \mathcal{V}^H \subset \mathcal{V}^h \):

\[ U^H = \mathcal{P}^H_h U^h = \mathcal{P}^H_h \mathcal{P}^H U \]

Assume the model is also valid for this subspace:

\[ \text{Find } U^H \in \mathcal{V}^H, \text{ such that } \forall W^H \in \mathcal{V}^H \subset \mathcal{V}^h, \]
\[ B(W^H, U^H) + M(W^H, U^H; H, c) = F(W^H) \]

Subtracting original equation, yields \( \forall W^H \in \mathcal{V}^H \):

\[ M(W^H, U^H; H, c) - M(W^H, U^h; h, c) = B(W^H, U^h) - B(W^H, U^H) \]

Relation used to estimate the model coefficients \( c \).
This results in model such that:

\[ U^h \approx \mathcal{P}^h U \]

Results - 1D convection diffusion

Exact model in terms of \( \tau \) is available:

* Linear \( \tau \sim h \) in the convective limit
* Quadratic \( \tau \sim h^2 \) in the diffusive limit

![Figure 1: Solution for linear and higher order elements](image1.png)

Multiple designs for \( \tau \) have been tested each able to exactly obey one or both limits.

![Figure 2: Modeling parameter \( \xi = \frac{20\tau}{h} \) vs viscosity \( Pe = \frac{ab}{\nu} \) for linear elements](image2.png)

The exact \( \tau \) is reasonably approximated even when the designed \( \tau \) does not posses the correct limiting behaviour.

References

P-2

Tenth Engineering Mechanics Symposium
Introduction

Fig. 1. The motor is propelled by sequentially applying voltage to opposite contacts. Left - conforming mesh and electric potential. The potential is applied to the nodes on the conductor-field interface; Center – conforming mesh distortion. Right - proposed non-conforming mesh.

Engineering devices such as Micro Electronic Mechanical Systems are often driven into motion by electrostatic fields. The design of these devices requires an accurate prediction of the coupling behaviour between the structure and the field. In general, this can only be done using computer simulations, for example, using finite element methods. In previous studies the finite element mesh of the electrostatic field had to conform to the structural mesh, causing the field mesh to follow the structure as it deforms. However, in case of large structural movements, mesh distortion of the field’s mesh becomes unacceptable. For instance, while simulating electrostatic micro-motors or electric switches the field’s mesh becomes severely distorted (Fig. 1).

The aim of this project is to develop monolithic finite element formulations for electrostatic-structural problems, which will allow the simulation of large motions of structures without the need for remeshing.

Methods

We propose [1] finite element formulation for the electrostatic structural problem, where the meshes of the structure and the field do not have to conform.

Fig. 2. Level set function, used to mark the boundary of the structure on the electric mesh.

The coupling between them is established using the so-called fictitious domain method, known from fluid structure interaction modelling, and level sets, that allows to mark the boundary of the structure on the electric mesh (Fig. 2).

The novelty of the proposed formulation is that it is based on a fully monolithic approach, allows independent discretization of the structure and the field and yet it is derived from the consistent energy of the coupled system. The latter is especially important since it allows a natural derivation of the electrostatic force and the full stiffness of the system.

Results

This formulation was applied to simulate electrostatically actuated switch.

Fig. 3. Simulation of an electric switch. The switch is a clamped beam that is attracted to the rigid surface by an electrostatic force.

This result was validated against the formulation of Rochus and Rixen [2].

Conclusions

• A novel, fully coupled Eulerian – Lagrangian method for electrostatic-structural coupling.
• Advantages: large displacements and consistent stiffness matrix (can be used for modal analysis, simulation of unstable behaviour and design sensitivity).
• Future work: accuracy in sharp corners and 3D formulation.

References

Isothermal simulation of an aluminum extrusion process with a multi-hole die
W. Assaad, H.J.M. Geijsetelaers, J. Huëtink
Faculty of Engineering Technology, University of Twente
P.O. Box 217, 7500 AE Enschede, The Netherlands
phone: +31-(0)53-4894069, email: w.assaad@ctw.utwente.nl

Introduction
In aluminum extrusion roadmap, a number of research areas were defined to improve the product functionality such as reducing the cost and decreasing the construction complexity. Achieving improvements within these areas can be accomplished through process modeling and simulation. For example, the aluminum extrusion for four L-shaped profiles with two different thickness is studied. Four different pockets are constructed in the die.

Objective
The simulation aims at: (1) exploiting FEM codes capabilities and users’ knowledge in the simulation of an industrial extrusion process, (2) checking the effect of pocket shape on process behavior, (3) checking the effect of profile thickness on pocket effectiveness.

Method
The die is assumed to be rigid and boundary conditions are applied to the billet. The bearing area is modelled by an average normal construction. Finally the billet is descretized with 10 nodes tetrahedron element where each node has 3 dof and an ALE/eulerian formulation is applied.

Results
In fact, the results are predicted after the die is being filled. The steady state profiles’ velocities and the extrusion force are plotted as shown in figures 2 and 3.

Discussion
The simulation takes quite a long time due to the large number of degrees of freedom and the usage of an iterative solver. It is observed from the current simulation that the influence of the pocket’s shape on the process behavior is obvious but the influence of the profile thickness on the pocket effectiveness is not recognized.

Figure 1: Boundary conditions applied on the billet.

Figure 2: Velocity distribution for 2mm and 3mm profiles’ thickness.

Figure 3: Extrusion force versus ram’s stroke.
Introduction
Because of their superior properties advanced high strength steels (AHSS), such as steels with transforming metastable phases, are widely used for various applications in the range from automotive parts to medical equipment and domestic appliances.
These materials exhibit complex behavior: their engineering scale response to mechanical loading during processing and service are highly dependent on the microstructural features, whereas microstructural properties may evolve during the mechanical loading, e.g. martensitic transformation.

The project aims to predict the behavior of metastable austenitic steels and provide input for optimization of the production processes.

Method and micromechanical model
The micro-level single grain transformation model is employed within the multi-scale computational framework (Figure 2).

At the finest scale the model resolves the evolution of martensitic volume fraction $\xi$ and the behavior of one transforming martensitic variant for a given total gradient deformation tensor $\vec{F}$. The model consists of

- Averaging rules
- Constitutive equations for each phase (austenite and martensite)
- Interface interaction relations
- Transformation criterion

Next, averaging over all 24 martensitic variants is performed to capture behavior of a transforming austenitic grain.

Results and future work
Interaction of plastic deformation and transformation is complex. The following effects are considered: plastic deformation of austenite produces additional nucleation sites (promotes the transformation); dislocation foresting in austenite around the interface might suppress the interface movement (retards the transformation). Based on this phenomenological considerations parametric transformation barrier function introduced.

Results obtained for various transformation barrier function parameters on uniaxial tensile test of a single crystal show that various aspects of transformation may be captured. Resulting shape of martensitic volume fraction evolution is in qualitative agreement with experimental observations.

Future work includes:
- Extension of research to polycrystalline case based on experimentally observed crystallographic data
- Characterization of the model parameters on uniaxial tension data for Nanoflex™ and comparison of simulations with experiments
Convergent Anti-Windup Controller Design: Experimental Results

R.A. van den Berg, A.Y. Pogromsky, J.E. Rooda
Eindhoven University of Technology
Department of Mechanical Engineering
P.O. Box 513, NL 5600 MB Eindhoven
phone +31-(0)40-2473360, e-mail R.A.v.d.Berg@tue.nl

Introduction
Consider the PI-controlled integrator plant with actuator saturation given in Figure 1, which can be described by the following state-space notation:

\[
\begin{align*}
\dot{x} &= Ax - B \text{sat}(u) + Fw \\
u &= Cx + Dw \\
y &= \begin{bmatrix} 1 & 0 \end{bmatrix} x
\end{align*}
\]  

where \(x \in \mathbb{R}^2\) denotes the state, \(w \in \mathbb{R}\) the reference input, \(u \in \mathbb{R}\) the controller output, \(y \in \mathbb{R}\) the system output, and

\[
A = \begin{bmatrix}
0 & 0 \\
-1 & -K_A K_P
\end{bmatrix},
B = \begin{bmatrix}
-1 \\
-K_A
\end{bmatrix},
C = [-K_P, K_I],
D = K_P,
F = \begin{bmatrix}
0 & 0
\end{bmatrix},
\]

in which \(K_P\) and \(K_I\) represent the gains of the PI-controller and \(K_A\) the anti-windup gain.

Convergent Anti-Windup Design

Definition of uniform convergency
System 1 is said to be uniformly convergent if a solution \(\bar{x}(t)\) exists that satisfies:

- \(\bar{x}(t)\) is defined and bounded for all \(t\);
- \(\bar{x}(t)\) is globally uniformly asymptotically stable for any allowable input \(w(t)\).

Theorem 1 If \(K_A > 1/K_P\) then system (1) is uniformly convergent for all harmonic inputs \(w(t)\) [1].

Experimental Results
For the experiment, the controller parameters are set to \(K_I = 20\) and \(K_P = 10\), and \(w(t) = \sin(t)\). Figures 2 and 3 show the system output \(r\) as a function of time for four different initial conditions and respectively \(K_A = 0 < 1/K_P\) and \(K_A = 0.2 > 1/K_P\). These results are in accordance with Theorem 1.

Figure 1: Anti-windup system

Objectives
1. Find conditions for \(K_A\) under which system (1) is convergent.
2. Validate these findings using experiments.

References
Development of an Artificial Miniature Flying Device
C.T. Bolsman*, J. F. L. Goosen and F. van Keulen
Delft University of Technology,
Faculty of Mechanical, Maritime and Materials Engineering, Mekelweg 2, 2628 CD Delft
phone +31-(0)15 27 83522, *e-mail c.t.bolsman@tudelft.nl

Introduction
The Atalanta program, of which this PhD project is part, aims at the development of an Flapping Wing Micro Air Vehicle (FMAV). This artificial insect is a demonstrator for the design and control of complex and adaptable systems. The overall program includes all components required for such a device, such as sensors, actuators, data management in distributed systems, power storage and management, reliability of complex systems, etc.

Energy
Starting from the chosen the design point the wing length and flapping frequency are design variables. Generally larger wings require less power to sustain a given mass, see Ellington [2]. However, since the power of the intended linear actuators is frequency dependent, increasing the wing size to very large is not the optimal solution in overall efficiency. Fig. 3 shows the design space for the wings. The development of the resonating structure cannot be seen separate from the choice of actuator. Currently electromagnetic actuators are used due to practical reasons. In a later stage Electro Active Polymer (EAP) or piezoelectric actuators might be employed.

Insects
Insects are very inspiring for the development of the wing actuation mechanism. Especially modern insects have a thorax structure that is a damped resonator, see Greenewalt [1]. The resonance is used to reduce the inertial cost of the wing movement. It is very beneficial to reproduce such a system for the actuation of the wings in a FMAV. An diagrammatic overview of the thorax cross-section in insects is shown in Fig. 2. Fig. 1 shows how to place this cross-section within an insect. Note that the muscles are not directly connected to the wing but instead drive the thorax structure.

Prototypes
Prototypes are built based, on a ring-like structure which serves as the main energy storage in the resonator. Experimental work and computational modeling, both multi-body dynamics and FE-based, help to further insight and the design process. See Fig. 4 for examples.

References

Figure 1 : Area of interest
This project aims at the development of the wing actuation mechanism within the boundaries set by the overall program. The size of the FMAV should be 10 cm wingspan and 4 grams vehicle mass.

Figure 2 : Diagrammatic cross section of insect thorax

Figure 3 : Resonating prototypes
The aerodynamic power needed to sustain hovering flight for the current design point is approximately 0.25 W. The goal is to design a wing actuation mechanism that is able to couple the actuator to the wings by means a resonant system to reduce the inertial cost of wing movement, while successfully mimicking insect wing kinematics for efficient flight.

Figure 4 : Resonating prototypes
Introduction

Many applications run in the boundary lubrication regime e.g: cam-followers, piston liner combinations and transmissions. Wear prediction in this regime is complex due to the multi-physical nature of the problem.

Mild Wear

To protect the metallic surface, constant renewal of the surface layer is needed. As long as the removal and growth are in balance mild wear occurs. The reaction layer is build up from bulk material and additives. Bulk material is needed to rebuild the surface layer and removal of bulk material takes place through a chemical reaction. These layers are very thin: in the range of tens of nm, see Fig. 3, and thus low wear rates occur in the mild wear regime.

Objective

The objective of the project is to predict the effect wear will have on the surface on roughness level (nm). This will be done by combining the different physical and chemical phenomena on the surface in a multi-physics model.

References:

Massively Parallel Microsystems through Precision Replication
A. Boustheen, F.G.A. Homburg, J.E. Bullema* and A. Dietzel
Micro and Nano Scale Engineering
Eindhoven University of Technology
Faculty of Mechanical Engineering
P.O. Box 513, NL 5600MB Eindhoven
phone +31-(0)40 2473647, email a.boustheen@tue.nl

Introduction
Fabrication of active fluidic elements within a system enables multiple ways of manipulating fluids in microfluidic systems. A versatile device can be designed by incorporating a large number of active fluidic elements in a single system.

![Figure 1](a) Channel structures from Lab on a chip disk from Gyros. (b) An active microvalve embedded within the system will enable precise and timely control of fluids through the channel.

Objective
The aim (1) is to have a network of active fluidic elements in a system that also contains passive fluidic structures and sensors. (2) To develop a common technology enabling fabrication of fluidic devices for variety of applications.

Design Approach
The system is separated into three primary layers and a membrane. (1) Passive layer containing fluidic reservoirs and cavities for active elements, (2) Actuator layer with actuators, (3) Sensor layer consisting of sensors. The membrane functions as the actuating element.

Each layer will be structured only from one side. The system is intended to have much larger surface area in comparison to thickness.

Technologies
Different functional fluidic elements are decoupled and hence can be designed and fabricated using different technologies independent of each other for specific applications.

Laser ablation, Injection Molding, Hot embossing, as well as many more non conventional MEMS fabrication techniques will be explored in order to have a high process yield.

Conclusion
Layer based device structuring enables modular way of designing fluidic devices for specific applications. An integrated system with large number of fluidic actuators will open new applications in microfluidics.

* TNO Science and Industry Eindhoven
Accurate simulation of springback using adaptive integration

I.Burchitz, T.Meinders, J.Huëtink
Faculty of Engineering Technology, NIMR –University of Twente
P.O. Box 217, 7500 AE Enschede, The Netherlands
phone: +31-(0)53-4894069, email: i.a.burchitz@ctw.utwente.nl

Introduction

Error due to the numerical integration in thickness direction is yet another reason of common inaccuracy of springback prediction. Traditional schemes may require up to 50 integration points for reliable results of springback analysis. However, in simulations of sheet metal forming (Figure 1), increasing the number of integration points places high demands on computational costs and is very undesirable.

Figure 1 : Simulation of sheet metal forming.

Objective

Develop a strategy for adaptive through-thickness integration that can guarantee an accurate solution while using a limited number of integration points.

Outline of adaptive strategy

The developed adaptive strategy includes several algorithms that perform additional tasks during a simulation, i.e locate elastic-plastic transitions; adapt the location of integration points; update their internal variables and perform the actual integration [1].

(a) NUMISHEET’02 benchmark (b) top-hat section

Figure 2 : Tests used for the evaluation.

Results of evaluation

Performance of the adaptive integration strategy is evaluated using several test problems (Figure 2).

NUMISHEET’02 benchmark. Simulations of this test show that the traditional Gauss quadrature requires at least 20 integration points to minimise the numerical integration error (Figures 3 and 4). To achieve similar accuracy the adaptive scheme uses twice as less integration points.

Figure 3 : Results of simulations. Test a.

(a) XZ cross-section (b) scaled view

Figure 4 : Shape of the blank after springback. Test a.

Top-hat section. Satisfactory results are also obtained in simulations of the top-hat section test (Figure 5). This shows that the adaptive integration improves springback prediction at minimal costs.

Figure 5 : Results of simulations. Test b.

Future work

Some modifications are needed to make the adaptive strategy suitable for simulations of industrial products.

References

Influences of the heterogeneities of the cerebral cortex for traumatic brain injury

R.J.H. Cloots, J.A.W. van Dommelen, and M.G.D. Geers
Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven
tel: +31- (0)40-247 5701, e-mail: r.j.h.cloots@tue.nl

Introduction

Current numerical head models that are used to predict traumatic brain injury have no detailed geometry of the cerebrum (Fig. 1). Therefore, these head models have no direct link to tissue-based injury criteria. To investigate the influences of the heterogeneities of the cerebral cortex, a model has been developed with a detailed geometry of a small section of the cerebrum (Fig. 1b, red box, and Fig. 2a).

Model

Boundary conditions Three different heterogeneous models and one homogeneous model have been developed (Fig. 2a). The prescribed displacements on the bottom boundary are based on a linear interpolation of the displacements of the corners nodes. For the top boundary, a slip-condition has been used. The left and right boundaries are constrained by periodic boundary conditions. The loading conditions are obtained from a head model (Fig. 1a) simulation in two different ways. Loading condition 1 is calculated from the acceleration that is imposed on the head model (Fig 2b). Loading condition 2 is computed from the resultant displacements in the brain tissue of the head model (Fig. 2c).

Material model The cerebrospinal fluid is modeled as a low shear modulus, nearly incompressible elastic solid. For the brain tissue, an incompressible nonlinear viscoelastic constitutive model has been used [3]. This model has been adapted for compressibility.

Results

In the equivalent stress fields of the heterogeneous models, local peak stresses are observed (Fig. 3). These peak stresses do not exist in the equivalent stress fields of the homogeneous model.

Conclusions

The maximum peak equivalent stress values are increased by a factor of 1.3 to 1.9 due to the morphologic heterogeneities. Therefore, tissue-based injury criteria cannot be applied directly to current numerical head models.

References

Multi-scale computational homogenization of structured thin sheets

E.W.C. Coenen, V.G. Kouzenetsova, M.G.D. Geers
Eindhoven University of Technology
Faculty of Mechanical Engineering
P.O. Box 513, NL 5600 MB Eindhoven
phone +31-(0)40-2475169, email: E.W.C.Coenen@tue.nl

Introduction
Structured thin sheets are used in a variety of innovative applications, e.g. flexible displays. The development of these functional structures often calls for an analysis of the complex micro-macro structure-properties relations. The aim is to develop a computational homogenization technique for the multi-scale modelling of structured thin sheets.

Computational homogenization
Computational homogenization [2] is based on the solution of two nested boundary value problems (BVP), one for the macroscopic and one for the microscopic scale. Thus, the stress-strain response at a macroscopic material point is obtained from the behaviour of the underlying microstructure, see Fig. 2.

Examples
Microstructural analysis Microstructural RVEs have been subjected to different deformation modes, see Fig. 3.

Multi-scale analysis A transversely loaded heterogeneous elasto-plastic structured sheet, clamped at both ends, with a prescribed displacement \( w \) at the center is considered, Fig. 4.

Conclusion
Computational homogenization is versatile and powerful analysis tool for structured thin sheets with any, possibly very complex, periodic microstructure.

References
Introduction
Design of products and metal forming operations requires reliable predictions of the manufacturability and the (residual) product properties after forming.

Objective
To develop a microstructural model, that will capture the relevant microscale damage mechanisms present in ductile metals. This model should allow the assessment of the impact of a particular material microstructure or strain path on formability and, at the same time, provide input for macroscale models suitable for large scale simulations.

Ductile damage
Ductile fracture in metals has been observed to result from the nucleation, growth, and coalescence of voids. The microstructural features influencing the damage evolution are:

➤ Geometrical and multi-material aspects
  - Grain size and shape
  - Second phase particle distribution
  - Different iron-phases

➤ Constitutive material behaviour
  - Crystal anisotropy of iron matrix
  - Damage due to secondary void populations

➤ Boundary descriptions
  - Particle/matrix-interface decohesion
  - Grain boundary failure

Method
The modelling will consist of 3D representative volume element (RVE) containing a relatively small number of grains. RVEs are developed under the assumption of a periodic microstructure and separation of scales. The relevant microstructural features influencing the damage process will be modelled explicitly.

Outlook
Prescribing different strain paths to the RVE will provide homogenized stress-strain relations for macroscopic modelling. It will also give the possibility to evaluate separately the influence of damage softening and work hardening on the yielding and study the microstructural evolution, e.g. void growth under complex macroscopic loading.
Introduction
The challenge for engineers and designers of mechanical systems is to control wear because of the complexity and the losses caused to the industry. In the last decades the knowledge in material science and mechanical engineering increased considerable but still is problematic to predict the wear rate and how to reduce wear. In literature wear is described as: “wear is a dynamic process which incorporates surface and material properties, operating conditions, stresses, lubricant oil film and geometry”.

Objective
To develop a model which predicts friction in lubricated systems when wear takes place and validate this model by experiments.

Method
In design of machine elements it is important to know the transition from boundary (BL) to mixed lubrication (ML) and from mixed to complete fluid lubrication (EHL) which is presented in the Stribeck curve.

![Fig.1: Stribeck curve and lubrication regimes.](image)

The information from Fig.1 can be used to select the parameters so that the components of lubricated systems operate in a preferred regime to minimize or avoid wear. In [1] is described the model in which wear affects the Stribeck curve.

Results
Experimental work was performed on a pin-on-disc tribometer [Fig.2]

![Fig.2: Pin-on-disc tribometer.](image)

Friction as result of wear was measured under conditions: Load $F = 0.5-20$ N, sliding distance up to 200 km, room temperature, sliding velocity 0.05-1.15 m/s, lubricant viscosity $\eta = 0.02$ Pa·s.

![Surface before Surface after](image)

In Fig. 3: Ball and disc surfaces - wear tests.

In Fig. 4: the experimental and model results are depicted.

![Graph](image)

Literature
Multi-field topology optimization; strong coupling at the interface

N.P. van Dijk*, M. Langelaar, F. van Keulen
Delft University of Technology
Faculty of Mechanical, Maritime and Materials Engineering
Mekelweg 2, 2628 CD Delft
*tel: 015-2786818, email: N.P.vanDijk@tudelft.nl

Objective

The design of microsystem components often involves the interaction of multiple physical fields, like fluid-structure interaction or electrostatic-structural coupling. Although the physics involved are very different, the strong coupling at the interface is a similarity. The interaction of physical fields complicates the numerical modeling and especially the design optimization of these components. The objective is to develop a topology optimization method for multi-physics with strong coupling at the interface.

Methods

Topology optimization offers a flexible and versatile optimization technique. Instead of describing the design with a finite number of shape parameters, topology optimization allows for arbitrary shapes within the design domain. The resulting, possibly unconventional designs may improve our understanding of optimal structures. The usual ‘relaxed’ topology optimization uses intermediate densities to ensure the existence of solutions.

A model for electrostatic-structural coupling by Andreykiv [2] may be used in this context. A Euclidian approach is used to model the electrostatic domain and the structure is tracked by a combination of a fictitious domain and a level set. This enables the calculation of large displacements without remeshing. In Figure 3 some results of this method are displayed.

Future work

In the near future a shape optimization including electrostatic-structural coupling will be set up. This can be later extended to a full level-set based topology optimization. The definition of design sensitivities in a level-set method will be further examined.

References

Simulating the blowing of glass bottles using the boundary element method

W. Dijkstra
Eindhoven University of Technology
Department of Mathematics and computing science
P.O. Box 513, NL 5600 MB Eindhoven
phone +31-(0)40-2474328, email w.dijkstra@tue.nl

Introduction
In the manufacturing of glass bottles and jars a preform of hot liquid glass is blown to its final shape. We simulate this process with the Boundary Element Method. This method is very efficient as it only computes the flow at the surface of the glass.

Equations
Stokes equations:

\[ \eta \nabla^2 v - \nabla p + \rho g = 0, \]
\[ \nabla \cdot v = 0. \]

Slip conditions:

\[ v \cdot n = 0, \]
\[ v \cdot t = \frac{1}{\beta} (\sigma n) \cdot t, \quad x \in S_m. \]

Pressure conditions:

\[ p = p_1, \quad x \in S_i, \quad p = p_0, \quad x \in S_o. \]

Challenges
• Computations in 3D;
• Friction between glass and mould;
• Surface tension at the glass.

Results
We simulate the blowing of several test models. The surface is divided into linear triangular elements. Velocity and normal stress vary linearly over each element.

Discussion
The BEM is an appropriate numerical method to solve the blowing problem. The computation time is moderately short, keeping in mind the complex nature of the problem. Also the accuracy is quite good. A drawback is that the material properties of the glass have to be uniform in order to use the standard BEM.
Advanced Modeling of High Speed Micro Rotordynamics

E. Dikmen, P. J. M. van der Hoogt and A. de Boer

Institute of Mechanics, Processes and Control
Chair of Structural Dynamics and Acoustics
University of Twente
P.O. Box 217, 7500 AE Enschede, The Netherlands
Phone: +31-(0)53-4893405, email: e.dikmen@utwente.nl

Introduction

With the recent developments in microfabrication techniques, production of complex geometries are enabled. Then, development of micro scale systems becomes possible. A great number of researchers have been working on the development of such devices as micro electric motors, micro turbines, micro pumps, micro reaction wheels, micro gyroscopic sensors and micro spindles. These systems require high speed rotating parts to achieve the same performances in macro level. However classical rotor dynamic modeling approaches can not be sufficient due to the effects becoming crucial in small scale.

Objective

Some physical effects become more crucial in dynamics of small scale components. The viscous forces are more important at small scale. Heat transfer is another important aspect since micro devices operate in a different design space than large-scale machines. The high angular speeds \((10^5-10^6 \text{ rpm})\) also require untraditional levitation systems for low friction operation. The aim of this project is to develop dynamic analysis tools for the design of microsystems with high speed rotating parts considering multiphysical effects. Afterwards, the developed models are intended to be used for a specific application to assess their effectiveness. Finally, the sensitivity of the frequently encountered problems of rotordynamics such as imbalance and eccentricity will be analyzed.

Figure 1: Photograph of the 4.2-mm diameter microturbine [1]

Future Work

The activity plan for the near future is:

- Formulation of multiphysical problems such as fluid structure interaction and temperature effects.
- Coupling these models with the rotor dynamics using a FE code developed in UT.
- Validation of the developed methods with experiments.
- Development of analysis approaches for the support & bearing.

References


Figure 2: Test results of two microturbine devices-Device 2 was run to a higher speed and crashed due to the unstable hydrodynamic forces [2]
Predicting solder reliability by microstructural modeling

M. Erinc, P.J.G. Schreurs and M.G.D. Geers
Eindhoven University of Technology, Department of Mechanical Engineering
e-mail: m.e.erinc@tue.nl

Introduction
In BGA packages, the corners of the package are exposed to highest strains arising from CTE mismatches and warpage. As a result of miniaturization, the increasing influence of microscopic entities on the overall mechanical properties makes continuum material models for fatigue life predictions questionable.

Figure 1: In BGA packages, first corners fail.

Objective
This study aims to develop a 3D lead-free solder fatigue life prediction tool, incorporating the local crystallographical directions and initial defects.

Microstructural Modeling
Microstructure of various solder balls is discretized from OIM scans. Local crystallographical directions are assigned to grains. Cohesive elements are placed at the grain boundaries.

Figure 2: An example microstructural mesh based on OIM scans.

A 3D cz element is developed to simulate interfacial fatigue damage. Traction vectors are calculated as:

\[ T_i = k_i (1 - D_i) \Delta_i, \quad \text{where} \quad i = n, t_1, t_2 \quad (1) \]

The damage variable evolves according to:

\[ \dot{D}_i = c_i |\Delta_i| (1 - D_i + r_i)^m \left( \frac{|T_i|}{1 - D_i - \sigma_f} \right) \quad (2) \]

Validation
The numerical results are compared with experimental fatigue life analyses obtained from the industry. Initial defects are introduced in the mesh as they were statistically determined.

Figure 3: Comparison of experimental values (courtesy of Philips App. Tech, Eindhoven) with simulations.

Conclusions
3D solder joints are simulated incorporating the microstructure, local orientations and initial defects. Fatigue life is determined using cohesive zone based damage models. An adequate agreement between the numerical analyses and experiments is achieved.
Introduction and objective

The computational modelling of tow-steered laminates with overlaps [1] require the development of a shell element for generalized geometries based on curvilinear coordinates that is able to perform accurate analysis for panels subjected to mechanical and thermal loadings. Tow-steering is a novel laminate design concept that attempts to tailor the stiffness of a traditional composite laminates by using non traditional curvilinear fiber paths. Based on the construction technique, gaps and/or overlaps can be generated between neighboring tow courses. The attention is restricted to panels with overlaps and accurate analysis require Layerwise theories in order to have a complete fulfillment of the requirements related to multilayered structures.

Methods

Taking into account the Reissner Mixed Variational Theorem (1)

\[
\sum_{k=1}^{N_l} \int_{A_k} \left[ \delta e_{\rho}^{T} \sigma_{\rho C}^{k} + \delta e_{\rho}^{T} \sigma_{\rho M}^{k} + \delta \sigma_{nM}^{k} (\varepsilon_{\rho C}^{k} - \varepsilon_{\rho M}^{k}) \right] dA_k \, dz = \delta L_{C} - \delta L_{M}
\]

and introducing respectively the constitutive and geometric relations, the assumption for both the displacement and the transverse stress components of the \( k \)th layer, in the z-direction, according to the expansion (2) (in compact form) [2].

\[
\begin{align*}
\mathbf{u}^{k}(x, y, z) &= F_{k}(z) \mathbf{u}_{x}^{k}(x, y) + F_{k}(z) \mathbf{u}_{y}^{k}(x, y) + F_{k}(z) \mathbf{u}_{z}^{k}(x, y) = F_{k} \mathbf{u}_{z}^{k} \\
\mathbf{\sigma}_{n}^{k}(x, y, z) &= F_{k}(z) \mathbf{\sigma}_{nb}^{k}(x, y) + F_{k}(z) \mathbf{\sigma}_{mb}^{k}(x, y) + F_{k}(z) \mathbf{\sigma}_{nt}^{k}(x, y) = F_{k} \mathbf{\sigma}_{nt}^{k}
\end{align*}
\]

with \( r = 2, \ldots, N \) \( k = 1, 2, \ldots, N_{L} \)

(2)

the shape functions for the in-plane description and subsequently assembling at element level, the following governing equations are obtained:

\[
\begin{align*}
K_{uu} q + K_{u\alpha} f &= P_{u} \\
K_{\alpha u} q + K_{\alpha\alpha} f &= P_{\alpha}
\end{align*}
\]

(3)

where \( q \) and \( f \) are respectively the vectors of the displacements and transverse stresses nodal degrees of freedom. By means of the static condensation technique, the following final governing equation is obtained:

\[
\left( K_{uu} - K_{u\alpha} K_{\alpha\alpha}^{-1} K_{\alpha u} \right) q = P_{u} - K_{u\alpha} K_{\alpha\alpha}^{-1} P_{\alpha}
\]

(4)

Results and discussion

In order to validate the adopted formulation and the application of the Reissner Mixed Variational Theorem, a three layers plate subjected to a bi-sinusoidal pressure load has been analyzed with the implemented 9-nodes plate element for a thickness ratio \( S = 4 \), comparing the results with the analytical solution (AN) and the exact one[3]. As pointed out in Fig. 1, a Layersonic formulation is required in order to have an appropriate response in terms of transverse stresses (the acronyms L and E are respectively for Layerwise (LW) and Equivalent Single Layer theories (ESL)). Accurate results are obtained using the static condensation technique (M) in comparison with a Full Mixed Implementation (M FMI) and the classical formulation (D) based on the Principle of Virtual Displacement.

References


Inverse Modelling of Glass Blow Forming Processes

J. A. W. M. Groot and R. M. M. Mattheij
Eindhoven University of Technology
mail to: j.a.w.m.groot@tue.nl

Glass Blow Forming Process
1. A glass preform is brought into a mould,
2. pressurised air is let inside,
3. the glass is blown into a container shape.

Level Set Based Simulation Model
A convection problem for level sets is solved to track the glass-air interfaces:

\[
\frac{\partial \theta}{\partial t} + u \cdot \nabla \theta = 0.
\]

Vector field \( u \) represents the flow velocity, which follows from a Stokes flow problem for incompressible fluids:

\[
\nabla \cdot (\mu \nabla u) - \nabla p = \rho g
\]
\[
\nabla \cdot u = 0,
\]

where \( p \) is the pressure, \( \mu \) is the viscosity, \( \rho \) is the density and \( g \) is a body force.

Inverse Modelling

- the optimal preform that results in the container under certain conditions is sought,
- the preform can be used for industrial manufacturing of the containers.

An Inverse Method
A Levenberg-Marquardt algorithm is used to find a solution of the inverse problem. The model parameters to be solved are the control points of the initial glass-air interfaces.

1. Control points are used to describe the interfaces by splines or Bezier curves,
2. a safeguarded method is applied to calculate the level set function as a signed distance function w.r.t. the interfaces,
3. the level set function for the glass container is computed,
4. the positions of the control points are corrected.

Example: application to a 2D Convection Problem
- Convection problem level sets
- Constant axi-symmetric flow velocity
- Circular interfaces at given time (right-hand figure)
- Objective: find interface initial time

Objective level set function
Initial guess
Initial forward solution
Inverse solution
Final forward solution