FIDYST – Simulation of Fiber Dynamics for Nonwoven and Fiber Processes

Dr. Simone Gramsch, Dr. Walter Arne, Dr. Dietmar Hietel
Fraunhofer Institute for Industrial Mathematics
Kaiserslautern, Germany
Evolution and ...

„DNA orbit animated“ by Zephyris (Wikipedia)
... Innovation
“Deconstruction” of a Spunbond Process

8 PhD projects for the detailed study of different aspects of the nonwoven production process:

- **Optimal Melt Flow**
  - PhD: Leithäuser (2009 - 2013)
  - Advisor: Pinna (TU KL), Feßler (ITWM)

- **Viscous Jets**
  - PhD: Arne (2009 - 2012)
  - Advisor: Meister (Kassel), Marheineke (Erlangen), Wegener (ITWM)

- **Turbulence Reconstruction**
  - PhD: Hübsch (since 2011)
  - Advisor: Ritter (TU KL), Wegener (ITWM)

- **Fiber-Air Interaction**
  - PhD: Cibis (since 2010)
  - Advisor: Marheineke (Erlangen), Wegener (ITWM)

- **Fiber-Wall Interaction**
  - PhD: Schmeißer (since 2011)
  - Advisor: Hagen (TU KL), Wegener (ITWM), Hietel (ITWM)

- **Fiber-Droplet Interaction**
  - PhD: Schröder (2009 - 2013)
  - Advisor: Hagen (TU KL), Wegener (ITWM), Hietel (ITWM)

- **Stochastic Fiber Lay-Down Models**
  - PhD: Maringer (2009 - 2013)
  - Advisor: Klar (TU KL), Wegener (ITWM)

- **Analysis of Fiber Lay-Down Models**
  - PhD: Stilgenbauer (2010 - 2013)
  - Advisor: Grothaus (TU KL)
How do we model staple fibers and filaments?

\[
(\rho A) \frac{\partial^2}{\partial t^2} \mathbf{r} = \frac{\partial}{\partial s} \left( T \frac{\partial}{\partial s} \mathbf{r} - \frac{\partial}{\partial s} \left( (EI) \frac{\partial^2}{\partial s^2} \mathbf{r} \right) \right) + \mathbf{f}_{ext}
\]

\[
\| \frac{\partial}{\partial s} \mathbf{r} \| = 1
\]

- line density
- center-line of fiber
- tangential contact force
- external forces
- bending stiffness
How do air forces act on fibers?
FIDYST – Fiber Dynamics Simulation Tool

- Simulation of filaments or staple fibers
- Import of CFD data in EnSight Gold Case Format
- GUI for material data
- Fiber-Wall Contact
- Export of simulation results with enhanced postprocessing
FIDYST – which effects are included in FIDYST?

- force of inertia
- tension, bending
- gravity
- air drag due to
  - mean air velocities
  - turbulent air forces based on $k - \varepsilon$ - turbulence model
- contact forces (with walls)
- friction (at conveyor belt)
FIDYST – Simulation Results of a Spunbond Process
SURRO – Simulation & Evaluation of the Fiber Lay-down

Idea of the stochastic surrogate model*: 

- Filament lay-down = reference curve + stochastic process
- Parameter identification from a full (FIDYST) simulation
- Standard deviation in MD / CD are characteristic for tenacity

\[
\begin{align*}
\mathrm{d}\xi_t &= \tau(\alpha_t)\mathrm{d}t - \mathrm{d}\gamma_t \\
\mathrm{d}\alpha_t &= -\nabla B(\xi_t) \cdot \tau^\perp(\alpha_t)\mathrm{d}t + AdW_t
\end{align*}
\]

SURRO – Features

- Each fiber follows its own stochastic path
- Complex production processes with arbitrary number of rows in CD and spinning positions in each row in MD can easily be generated by a help assistant.
- Specify material parameters: titer, density, spinning speed …
- Complex motions of the conveyor belt (translatoric, oscillatory, rotatory)
SURRO – Parameter Study

- Curtain process with curling coefficient $A = 10, 20, 30, 40$ (l.t., r.t., l.b., r.b.)
- Spinning 4800 m/min, belt 200 m/min, deposition size MD 25 mm, CD 15 mm
SURRO – Analysis of Nonwoven Quality

- Evaluation of homogeneity, CV-Values
- Distributions in MD or CD
SURRO – Generation of 3D-Structure
How can we use such beautiful maths for industrial problems – or is it only beautiful, but useless?

Our mission: Modeling – Simulation – Optimization
Simulation Results of the Airlay Process of Autefa Solutions
Our mission: Modeling – Simulation – Optimization …
… of nonwoven production processes !!!

Dr. Raimund Wegener
Dr. Dietmar Hietel
Dr. Simone Gramsch
Dr. Robert Feßler
Johannes Schnebele
Sergey Antonov
Dr. Walter Arne
Dr. Christian Leithäuser