Tolerance management for composite parts

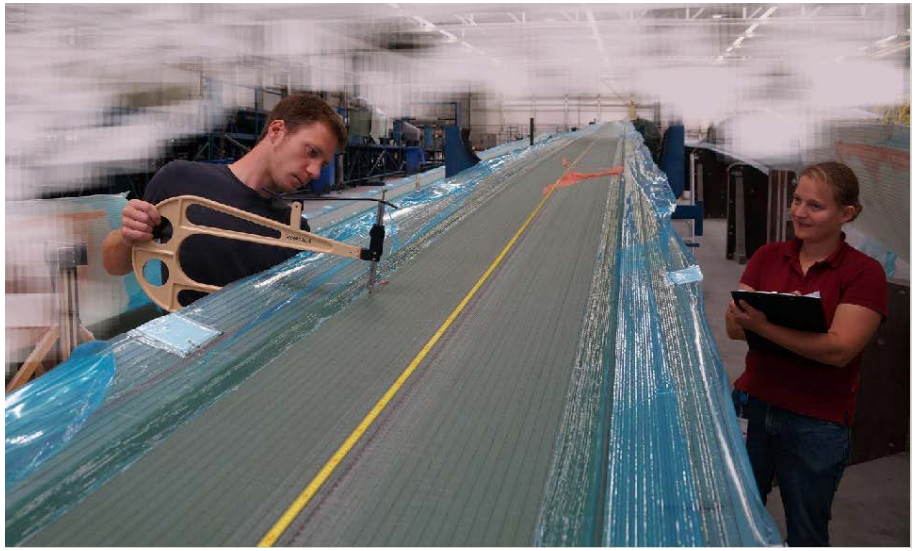
7th International Symposium on Composites Manufacturing for High Performance Applications
DLR Braunschweig, August 25, 2016

German Aerospace Center (DLR)
Institute of Composite Structures and Adaptive Systems
Department of Composite Technology

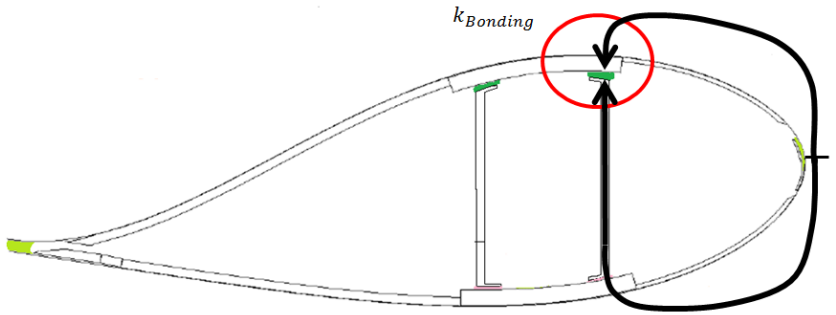
Birgit Wieland, Sven Ropte

Contents

- Motivation
- Tolerating structural elements
- Tolerance Management for composite parts
- The statistic approach
  - Key Characteristic and Parameter Inquiry
  - Impact Analysis
  - Tolerance Synthesis
  - Tolerance Analysis
  - Tolerance Synthesis - Process induced deformations
- Tolerance Management for large composite parts
- Conclusion



Motivation

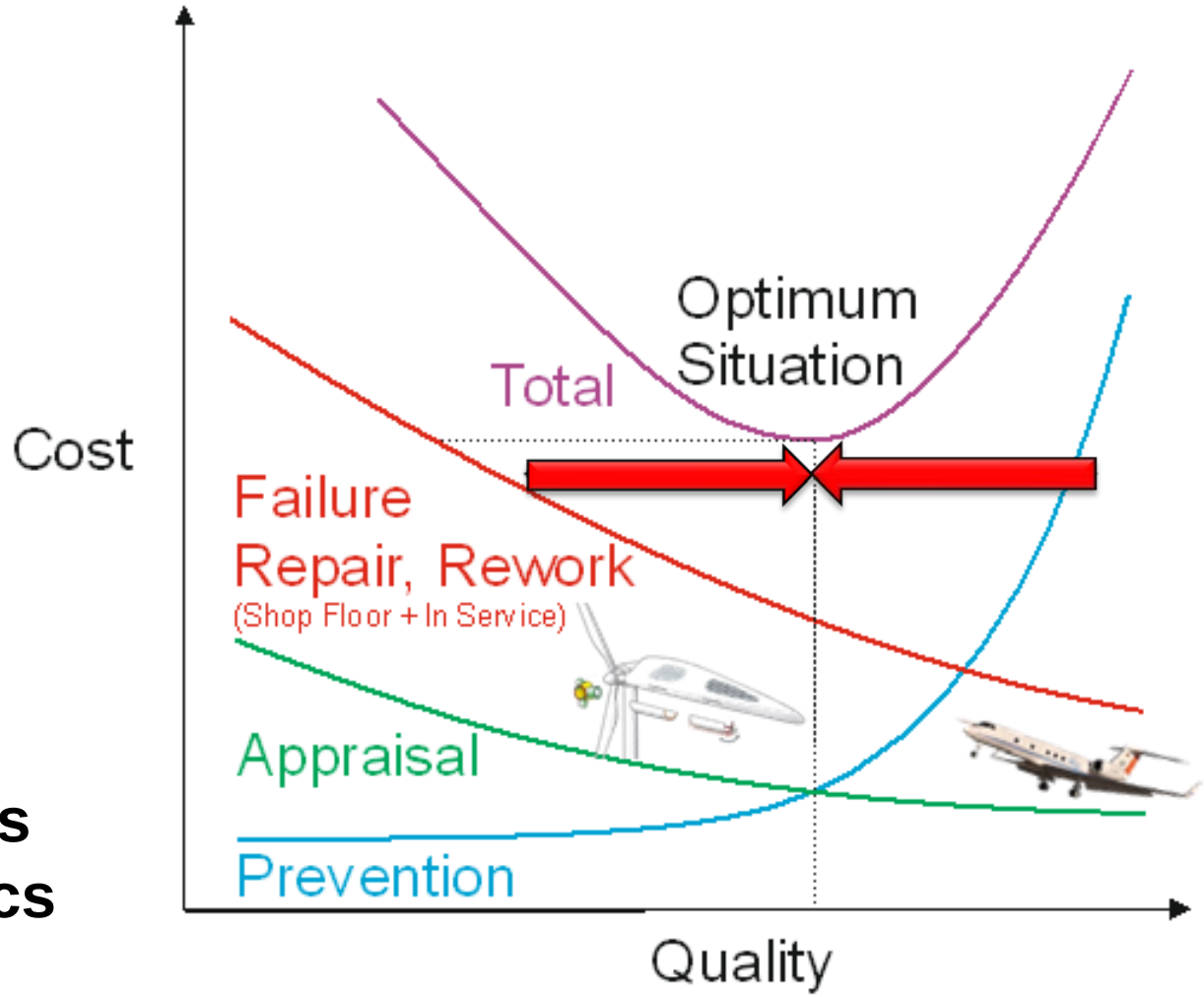


Critical detail: Bonding lines

- loss of components
- expensive rework

Reduction of Influence of parameters on critical details

How to identify the critical parameters and their impact on key characteristics and requirements?



Tolerating structural elements

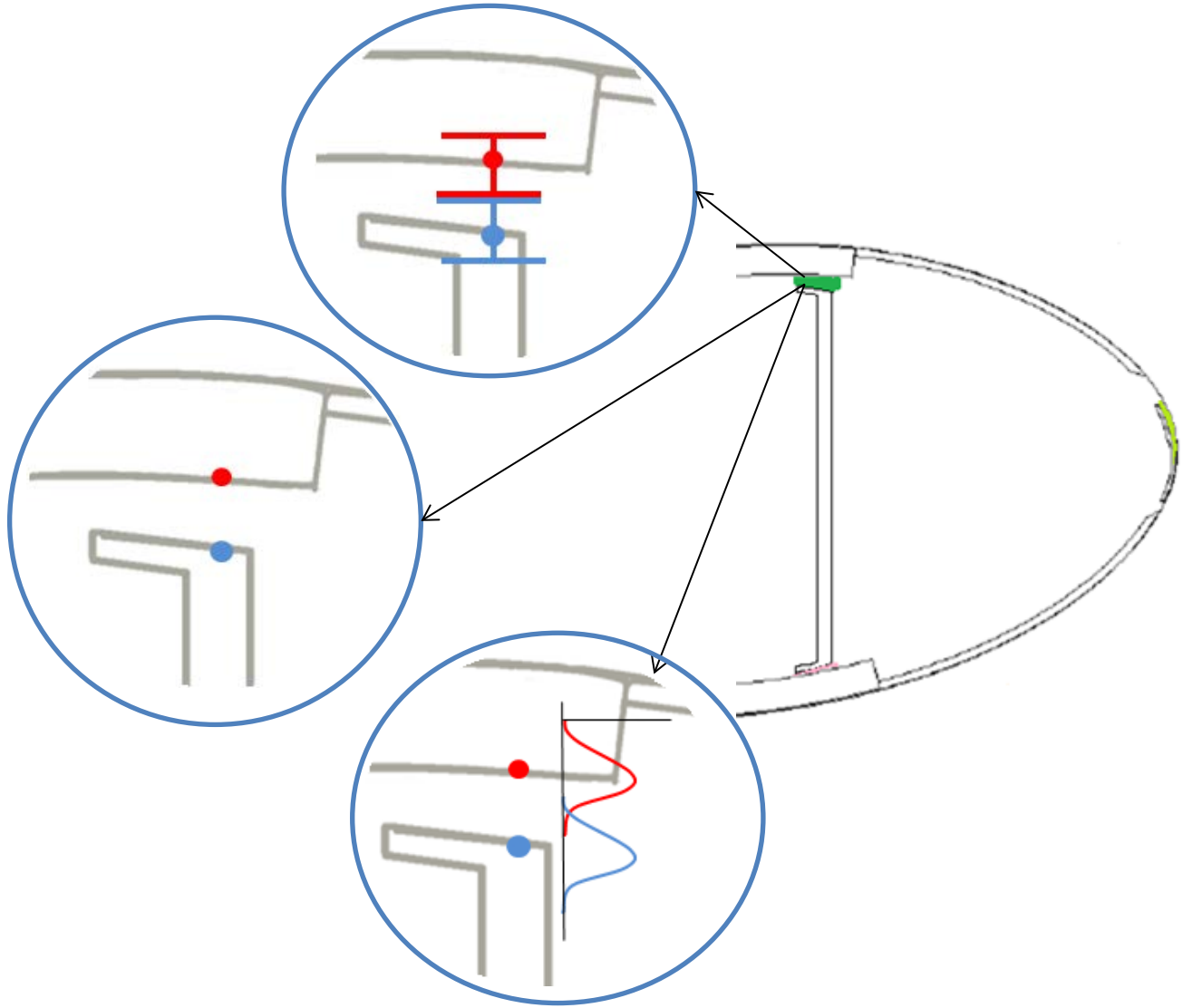
Bonding line of rotor blade has to be 1-15mm (according to certification)

Generalized Tolerance Chain

Parameter 1

Parameter 2

Transfer Function → Closing Tolerance



Tolerance principles:

- **Arithmetic**
  - ➢Worst Case Simulation
- **Randomly**
  - ➢Finding fitting pairs
- **Statistical**
  - ➢Probabilistic Simulation

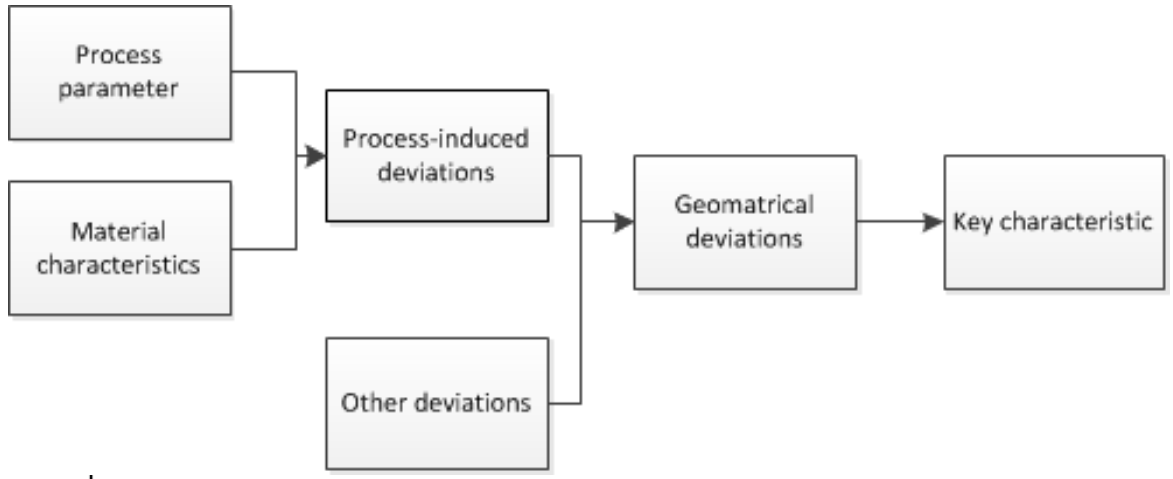
Tolerance Management for composite parts

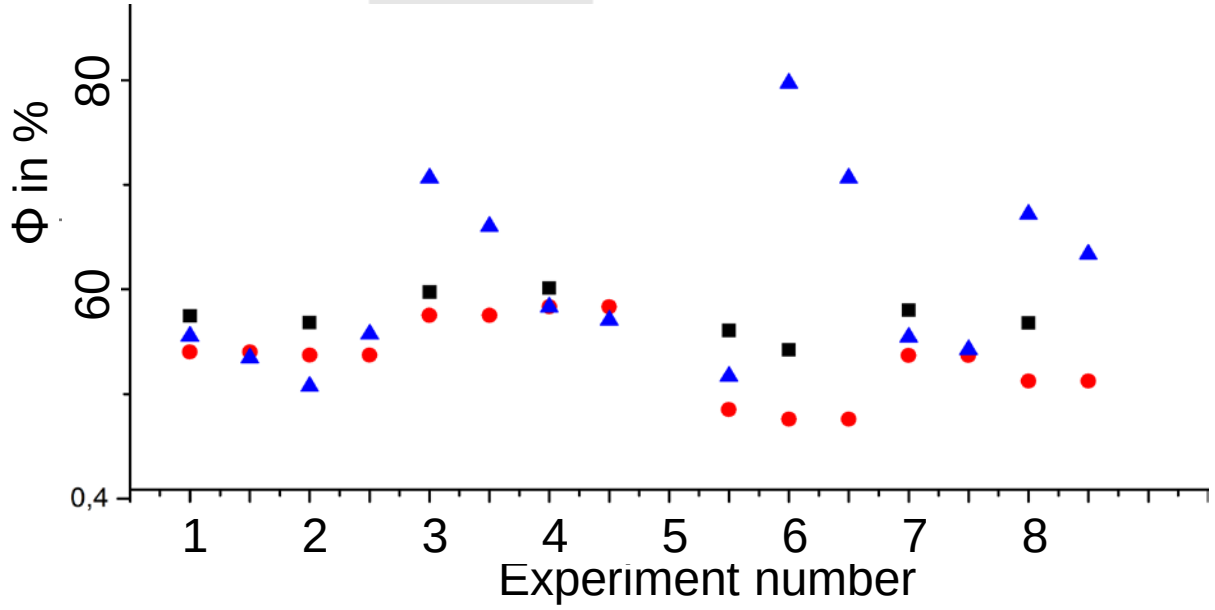
Special feature of Tolerance Chains for composite parts:

- Elements:
  - Process parameters
- Transfer Functions
  - Chemical Processes
  - Physical Processes

- Challenge:
  - Scattering of Properties and Parameters
  - Process-oriented Transfer functions

Tolerance management of composite parts is statistic!





The statistic approach

Finding Transfer functions for all influences of single Parameters within the physical dimension of the Key Characteristic

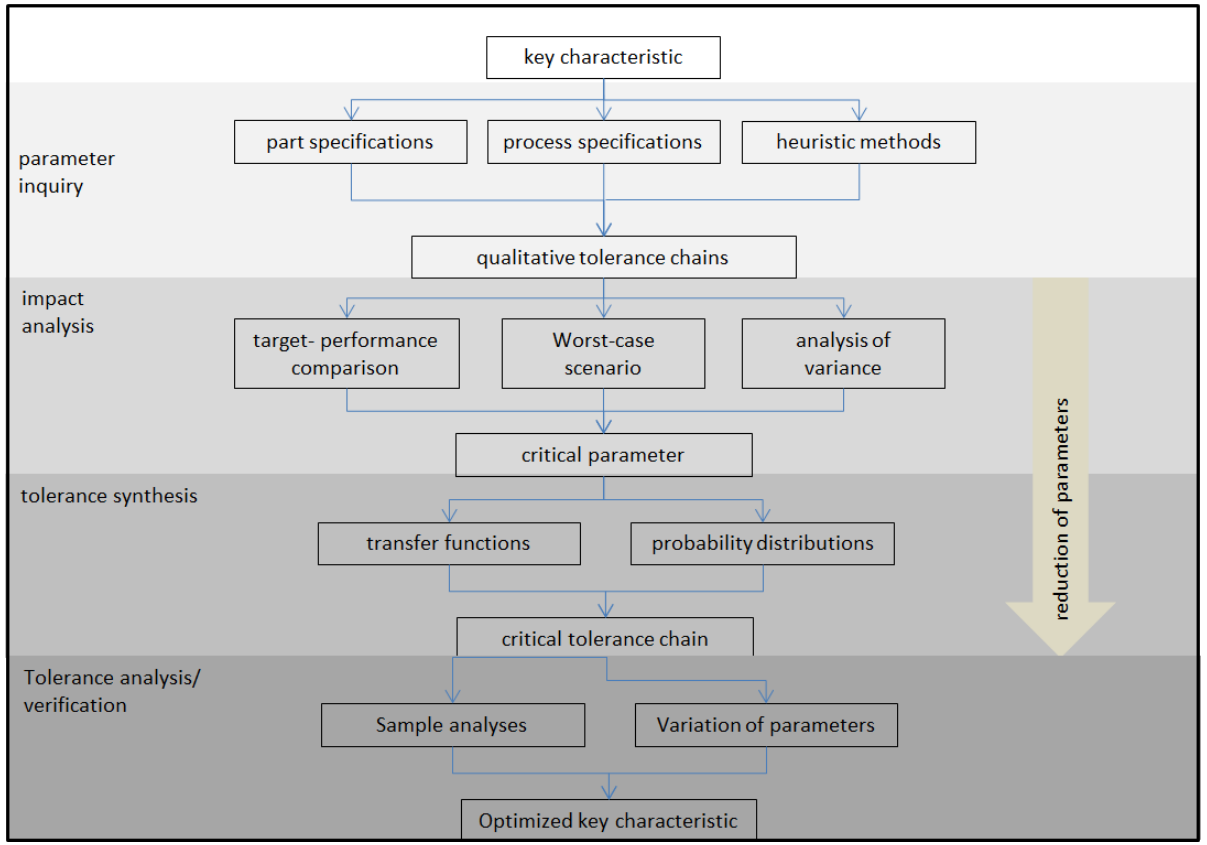
Key Characteristic

Parameter Inquiry

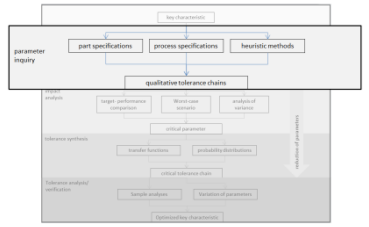
Impact Analysis

Tolerance Synthesis

Tolerance Analysis



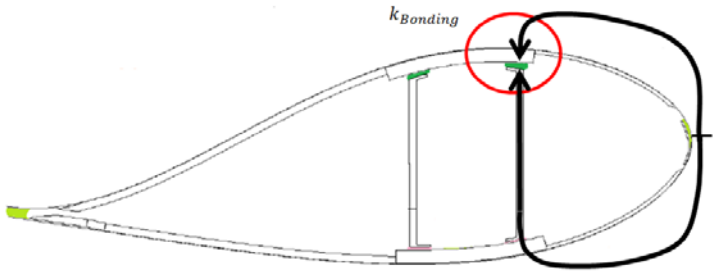
Optimized Process Parameters for Key Characteristic

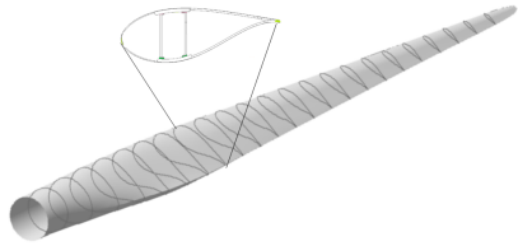


Key Characteristic and Parameter Inquiry

„Global“ key characteristic: Bonding line of rotor blade

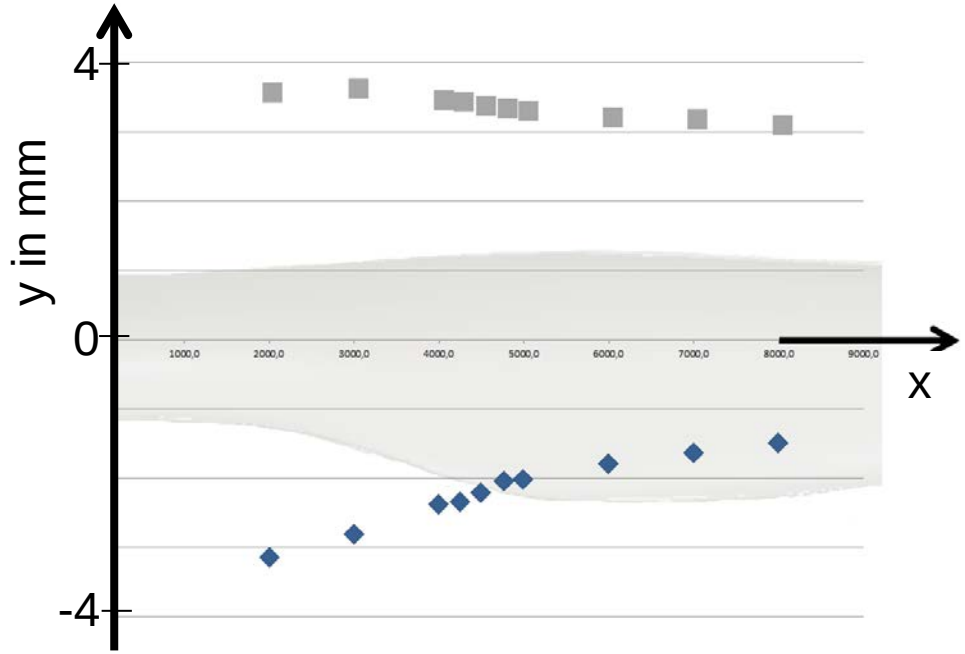
Critical Module: **Temperature**





Parameter Inquiry

- Input
  - Layup
  - Resin type
  - Fiber volume fraction
  - Heating system
  - Ambient temperature
  - Process temperature
- Output
  - Tooling geometry
  - Spring-Back /Spring-In
  - Thermal expansion
  - Material performance
  - …

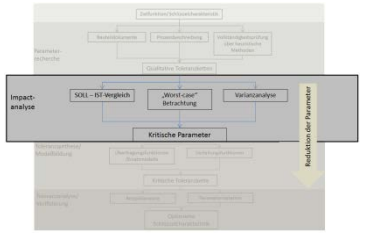


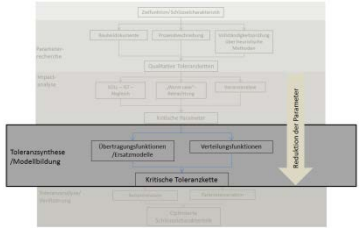
Impact Analysis

Prediction of Temperature:
T= T(x,y,z,t)

Input parameters:
- Material parameters
- Fiber volume fraction
- Process temperature

Statistical Experimental data:
- Temperature on tool surface
- Temperature on part surface
- Exothermic reaction





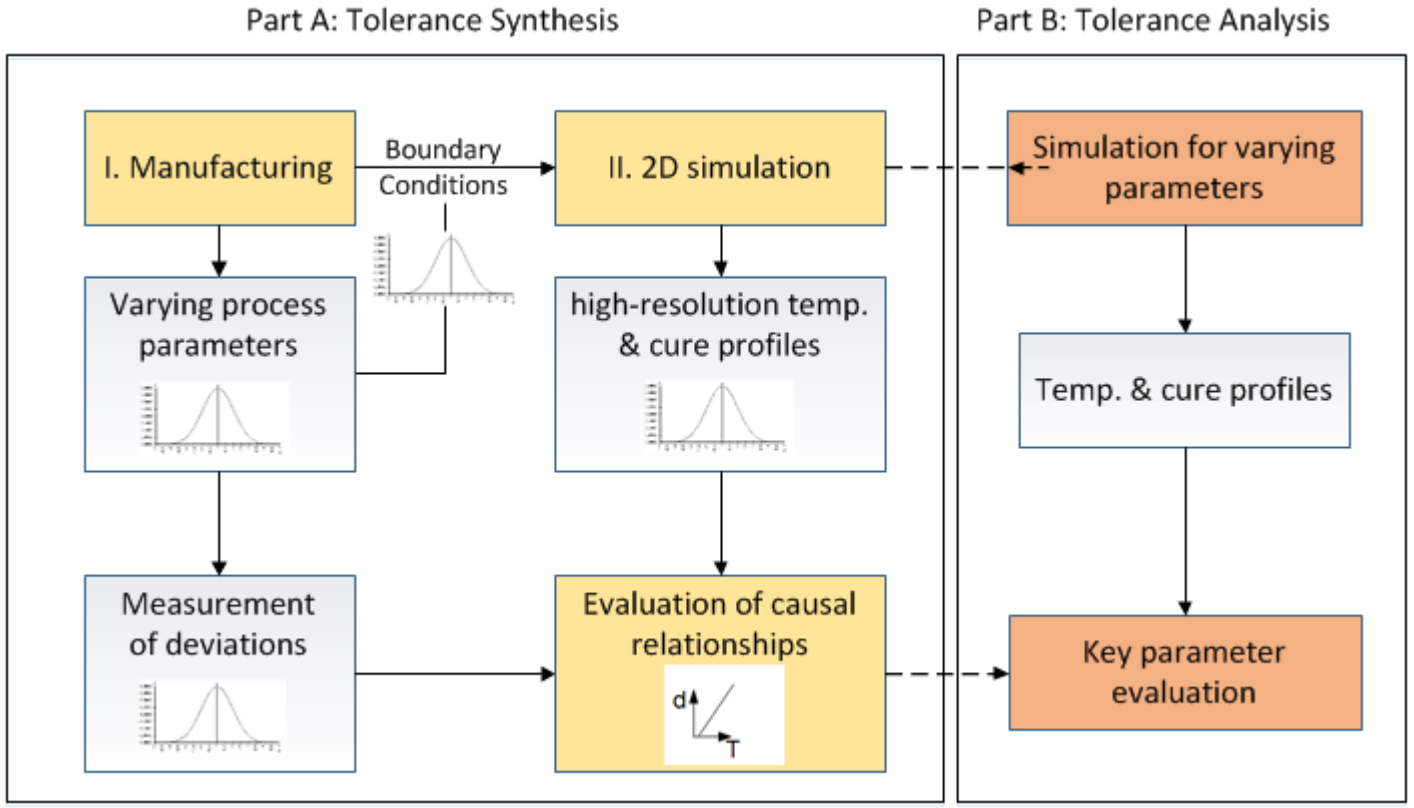
Tolerance Synthesis

Transfer Function:

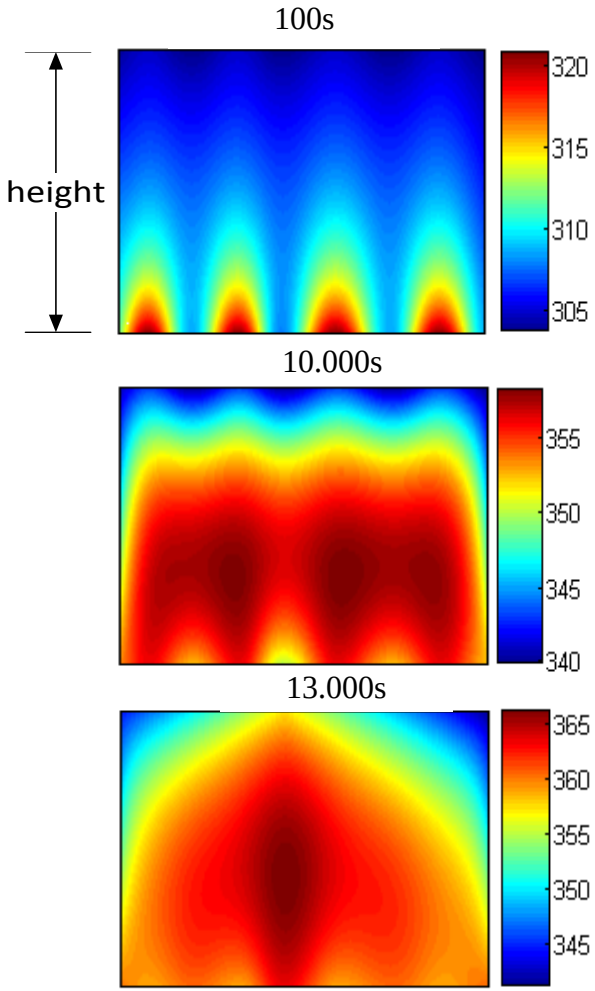
Fourier's law in differential form

$$\frac{\partial T}{\partial t} = a * \left(\frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{\dot{Q}_{Exoth}}{\rho\_Lam * c\_p}$$

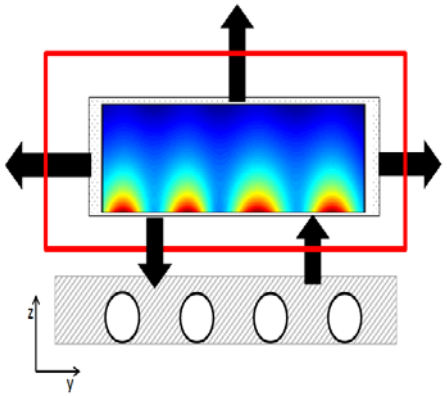
An implicit method delivering a numerical solution.

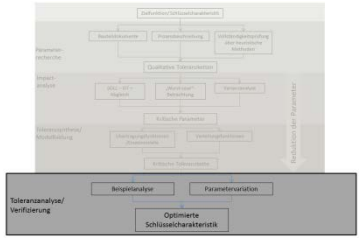


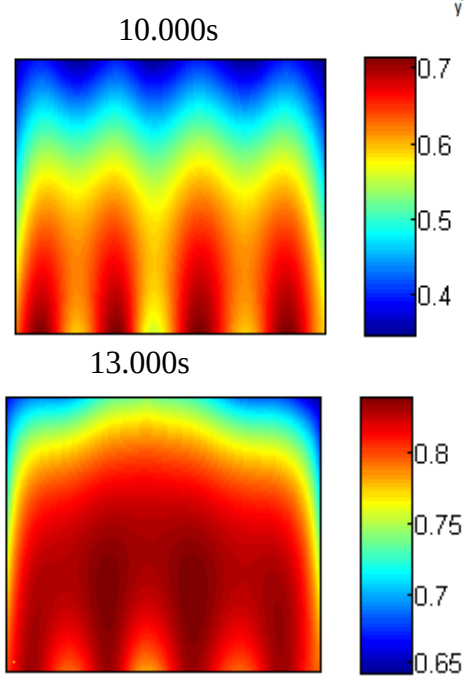
Tolerance Analysis



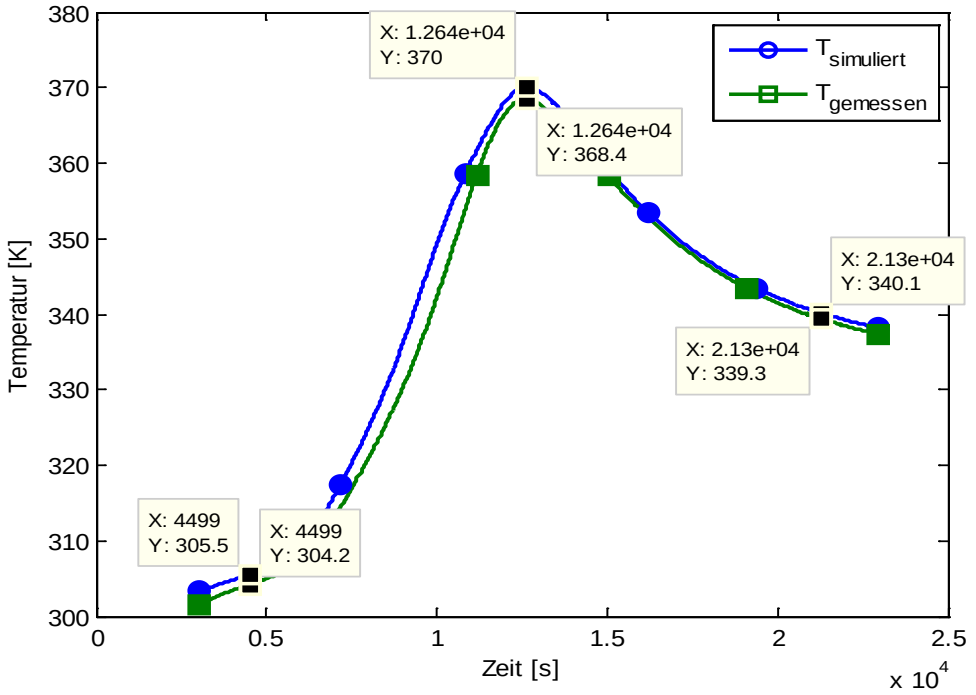
Temperature distribution for spar cap with 45 layers







Curing ratio distribution



Source: Masterthesis Sven Ropte

Tolerance Synthesis - Process induced deformations

Transfer Functions Temperature - geometrical deformation

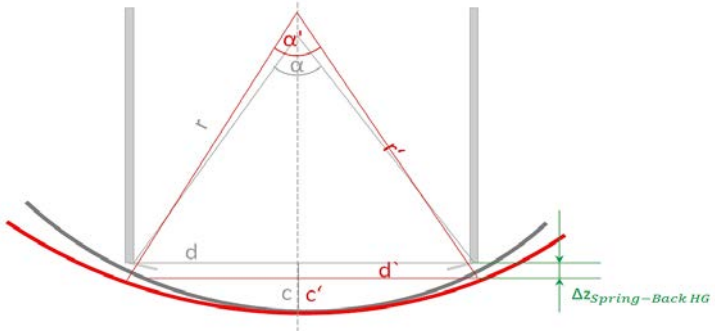
Hypothesis

Gradients in temperature distribution

Lead to gradients in curing ration

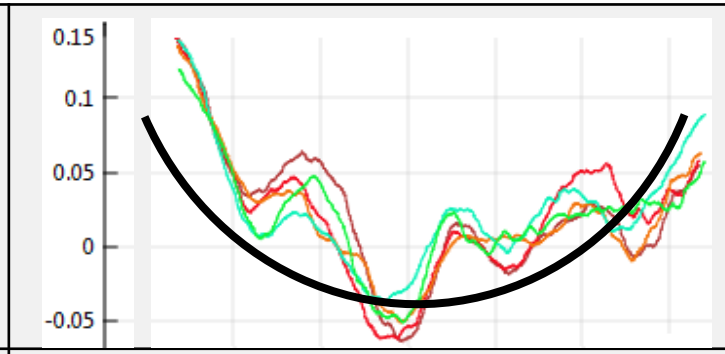
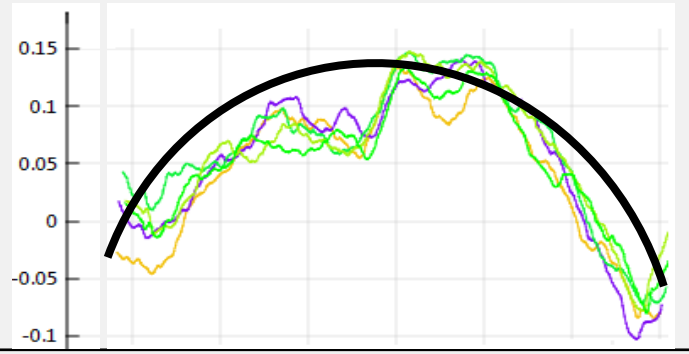
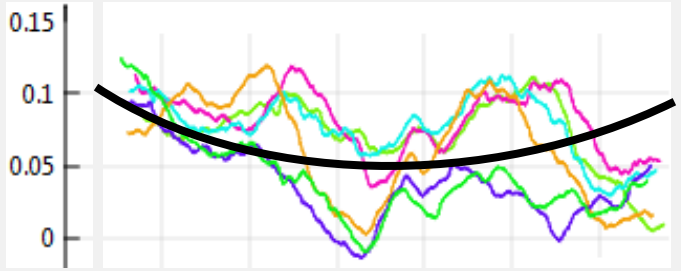
Lead to gradients in fiber volume fraction

Lead to **Spring Back**



Correlation between amount of layers and T_{PEAK} ?

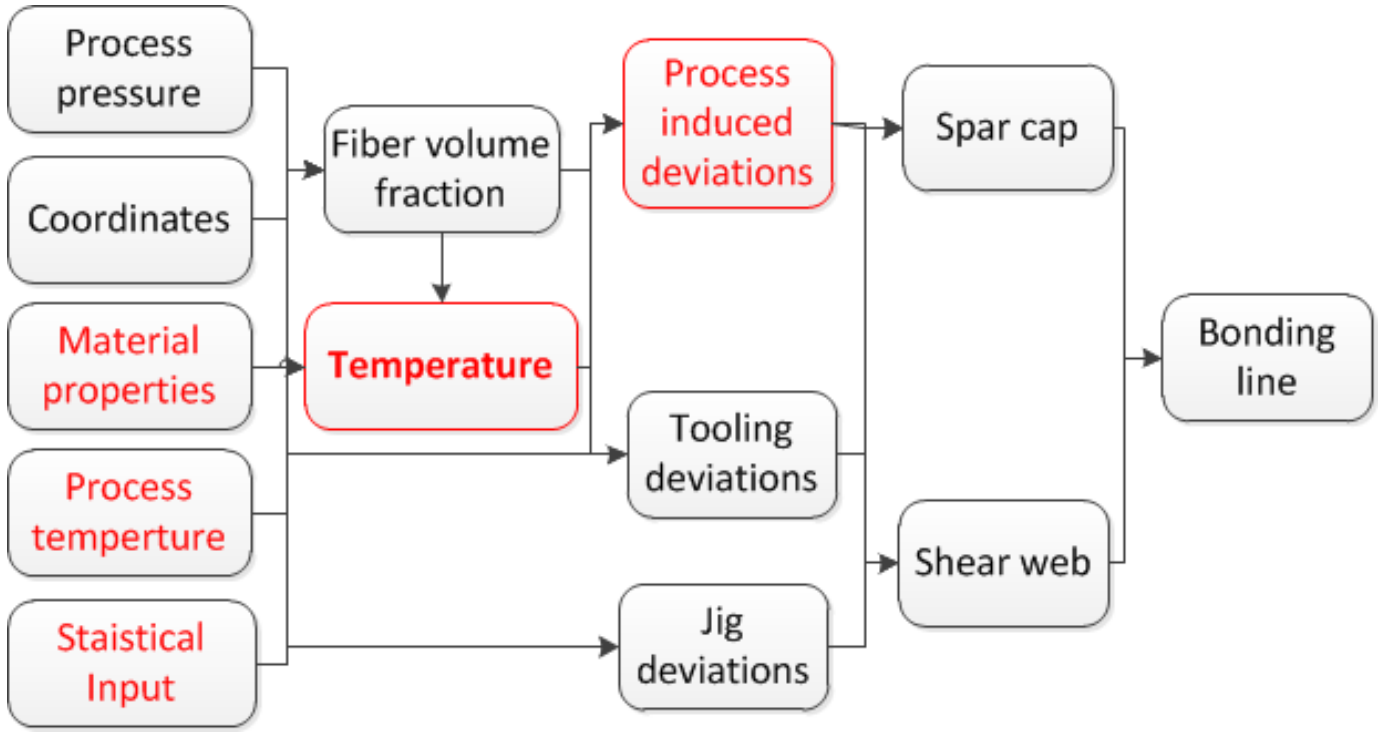
Correlation between T_{SET} and T_{PEAK}?

T_P = 55°C T_{PEAK} = 54,8°C 20 UD-Layers	
T_P = 85°C T_{PEAK} = 104,3°C 20 UD-Layers	
T_P = 75°C T_{PEAK} = 95,3°C 45 UD-Layers	

Tolerance management for large composite parts

Tolerance synthesis is finalized when the influence of all critical parameters can be described within the physical dimension of Key Characteristic

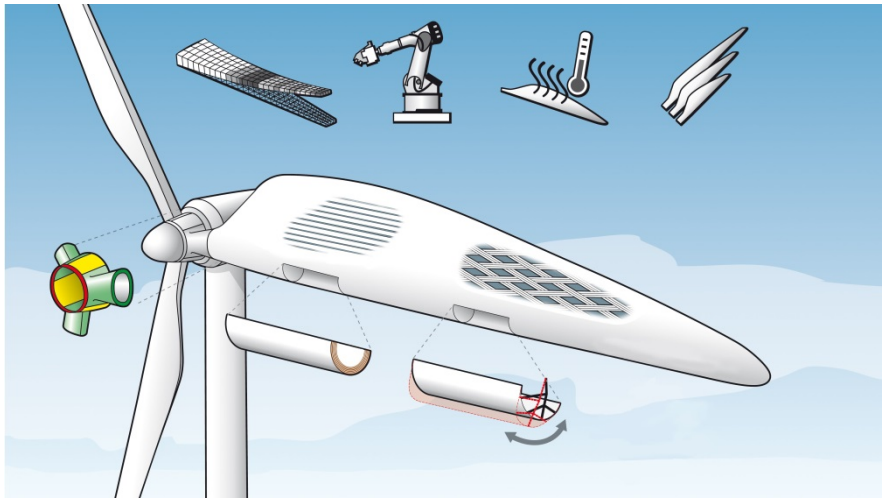
Tolerance analysis starts with the Key Characteristic and delivers optimized Input Parameters



IT IS AN ITERATIVE PROCESS !

Conclusion

- Reduction of Influence of parameters on critical details
- Tolerance management of composite parts is statistic because of scattered data points
- Transfer functions for all Parameters within the physical dimension of the Key Characteristic is necessary for optimization



Outlook

- Implementation of design optimization program to enlarge data bases with simulation results
- Implementation of additional modules for further production processes
- Compatibility with cost assessment tool

Dipl.-Ing. Birgit Wieland

Composite technology

German aerospace center

Institute of composite structures and adaptive systems

Lilienthalplatz 7
D-38108 Braunschweig

phone +49 531 295-2911

e-mail Birgit.Wieland@dlr.de

homepage www. DLR.de/FA/