Tailored Fibre Placement Technology – Optimisation and computation of CFRP structures

L. Aschenbrenner*, H. Temmen, R. Degenhardt***

***DLR, Institute of Composite Structures and Adaptive Systems**

****Airbus Deutschland**

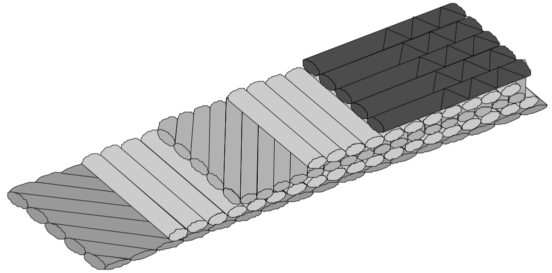
Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

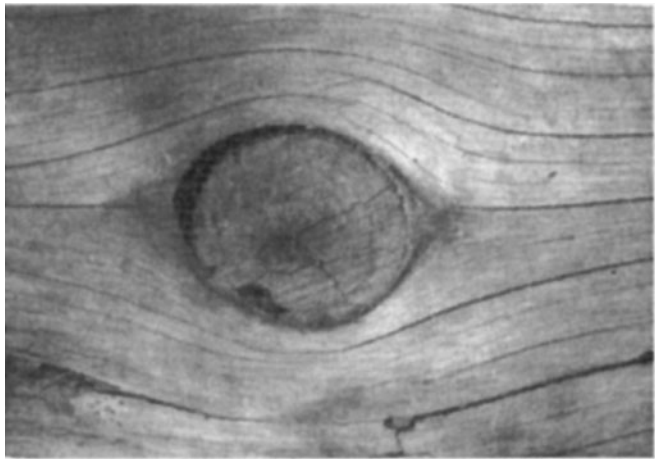
Outline

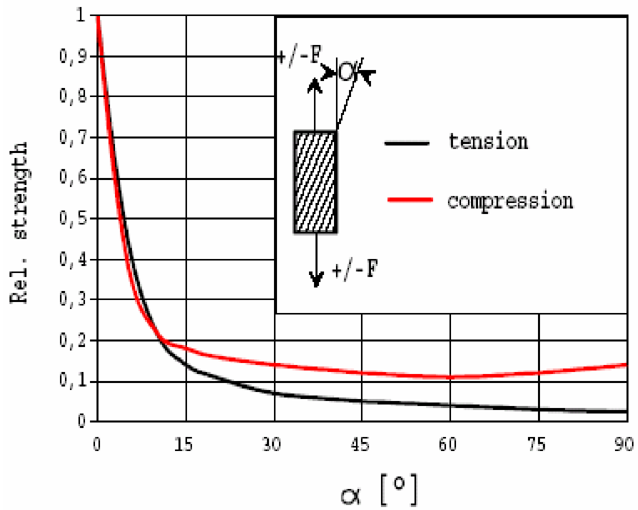
- Tailored Fibre Placement (TFP) Technology
- Projects on TFP
- Optimisation
- Application to a structural component
- Selected results of recent research
- Summary and Conclusions

Tailored Fibre Placement
Motivation

- In common composite structures fibre orientations are layer wise constant
- Anisotropic material properties are not fully exploited
- **T**ailored **F**ibre **P**lacement (TFP) follows the example of nature (bionic approach)





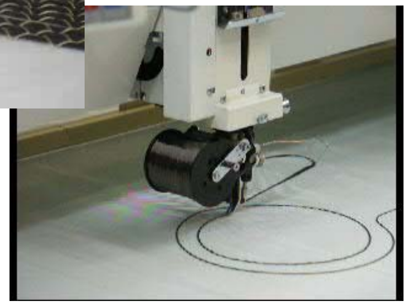


[www.hightex-dresden.de]

Tailored Fibre Placement Technology

- **T**ailored **F**ibre **P**lacement (TFP) is a textile process for production of fibre reinforced structures
- Rovings are stitched on e.g. fabric using highly efficient textile machines
- Rovings may be placed in almost any orientation. Calculated optimum fibre quantities and orientations can be realised

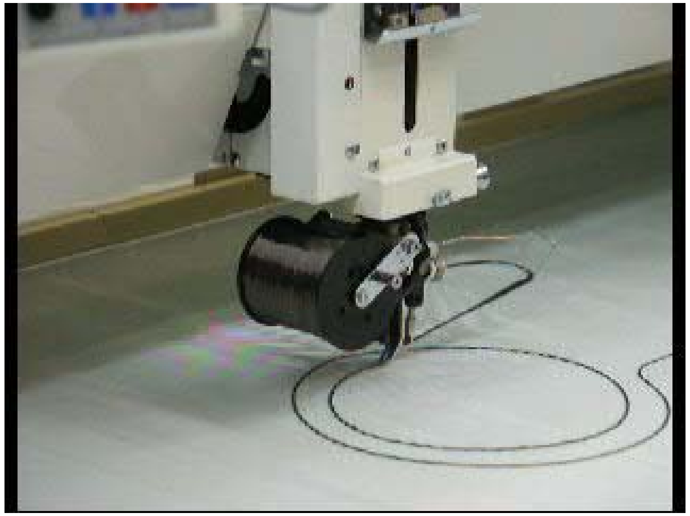




[www.hightex-dresden.de]

Tailored Fibre Placement Technology

- **T**ailored **F**ibre **P**lacement (TFP) is a textile process for production of fibre reinforced structures
- Rovings are stitched on e.g. fabric using highly efficient textile machines
- Rovings may be placed in almost any orientation. Calculated optimum fibre quantities and orientations can be realized



[www.hightex-dresden.de]

Overview projects on TFP

Project 2 **KRAFT**

(2003-2007)
Funding: Lufo III

TFP-Basic research investigations

→

Project 3 **EMIR**

(2003-2006)
Funding: Lufo III

Automatic TFP-Algorithm (TACO)

→

Project 4 **ROVING**

(2003-2006)
Funding: Lufo IIb and Germany

Automatic Determination of the roving distribution

↑ ↑ ↑

Project 1 **Design fundamentals for 3D reinforced composites**

(2000-2003)
Funding: German state Lower Saxony and Airbus Germany

TFP-Design tool TACO (not automated) and application on the HTP-connection beam

Overview projects on TFP

Project 2 **KRAFT**

(2003-2007)
Funding: Lufo III

TFP-Basic research investigations

Project 3 **EMIR**

(2003-2006)
Funding: Lufo III

Automatic TFP-Algorithm (TACO)

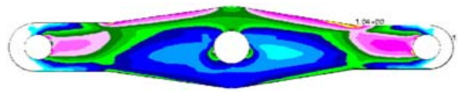
Project 4 **ROVING**

(2003-2006)
Funding: Lufo IIb and Germany

Automatic Determination of the roving distribution

Project 1 **Design fundamentals for 3D reinforced composites**

(2000-2003)
Funding: German state Lower Saxony and Airbus Germany

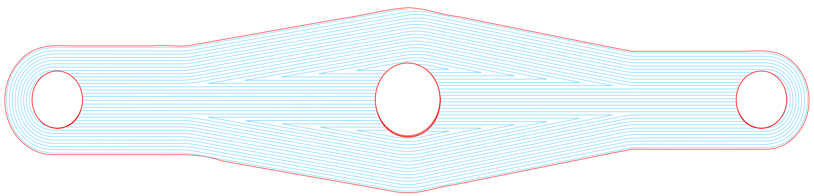


TFP-Design tool TACO (not automated) and application on the HTP-connection beam

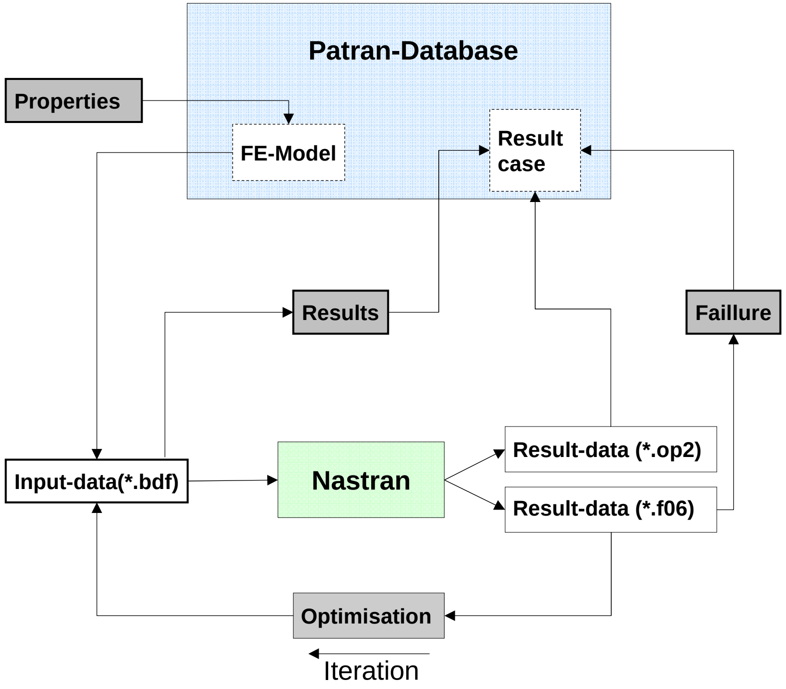
TFP Optimization Tool TACO

- Fibre orientations are changed within a user-defined layer of a FE model
- Fibres are aligned as closely as possible to the direction of the principal stresses
- TACO is embedded in MSC PATRAN / NASTRAN environment for industrial applicability

Rovings parallel to stress trajectories



TACO flow chart

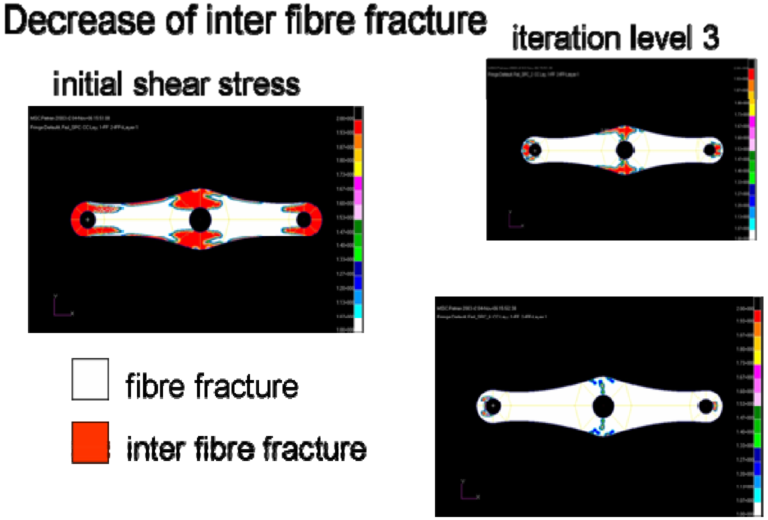


Optimisation of TFP-structure

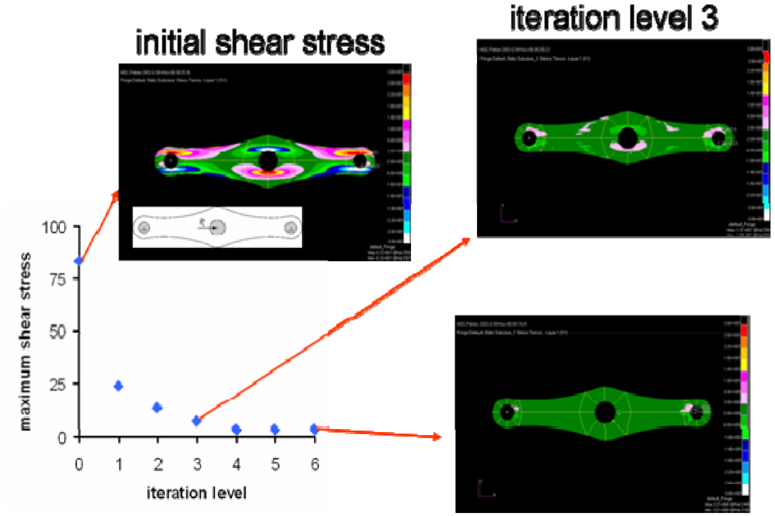
Application of TACO

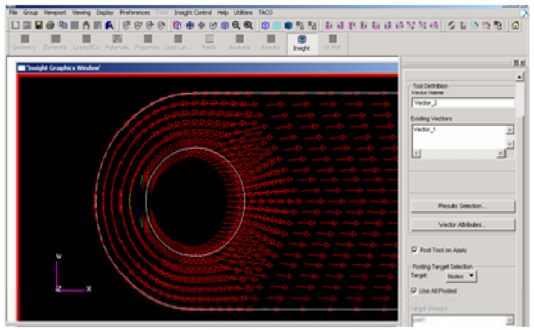
1. Initial stress computation
2. Optimisation of roving orientation - Iteration
3. Failure analysis
4. Output of roving orientations

Decrease of inter fibre fracture



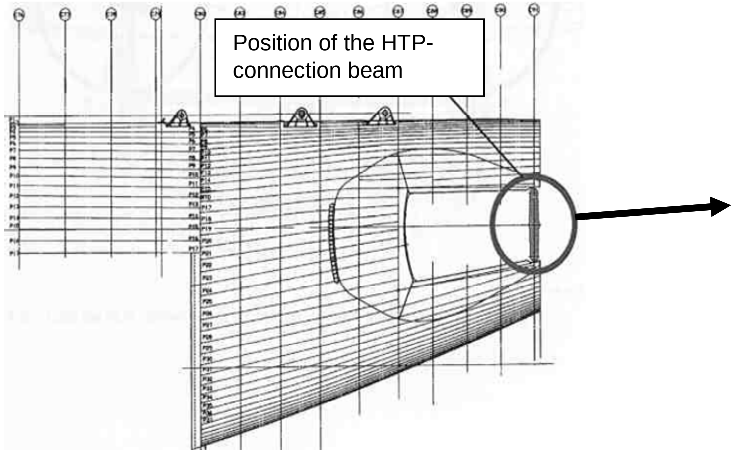
Decrease of maximum shear stress

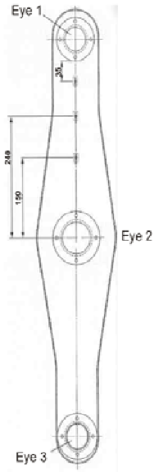




Application on the HTP connection beam

- TACO optimisation of a horizontal tail plane (HTP) connection beam as part of the Airbus A340 fuselage structure

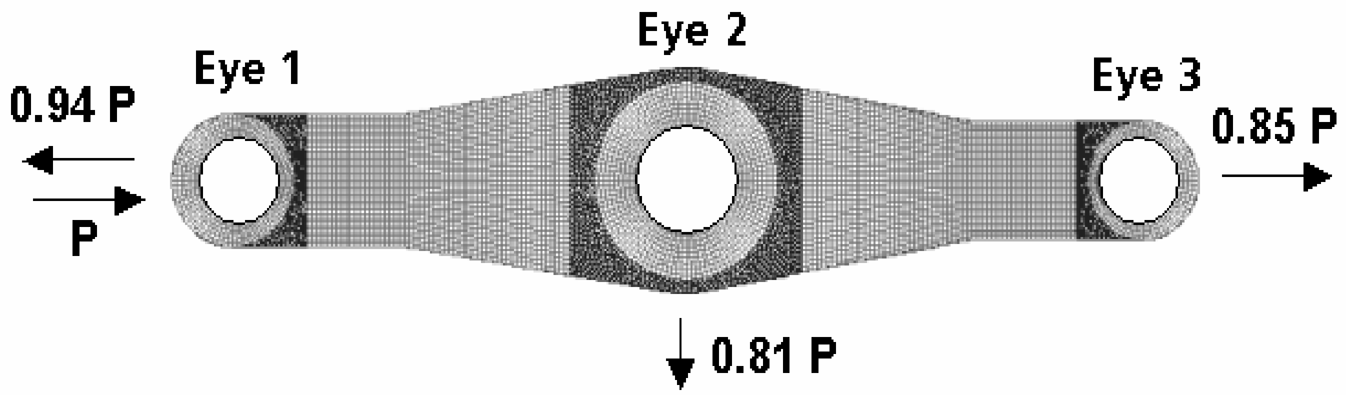




Sketch of the A340 HTP-connection beam.

- For the optimisation, only the orientations of the rovings and their lay-up were considered
- For simplification, TACO was applied to optimize the 0°-layers only. The 90°-layers were omitted. The ±45°-layers were left unchanged.

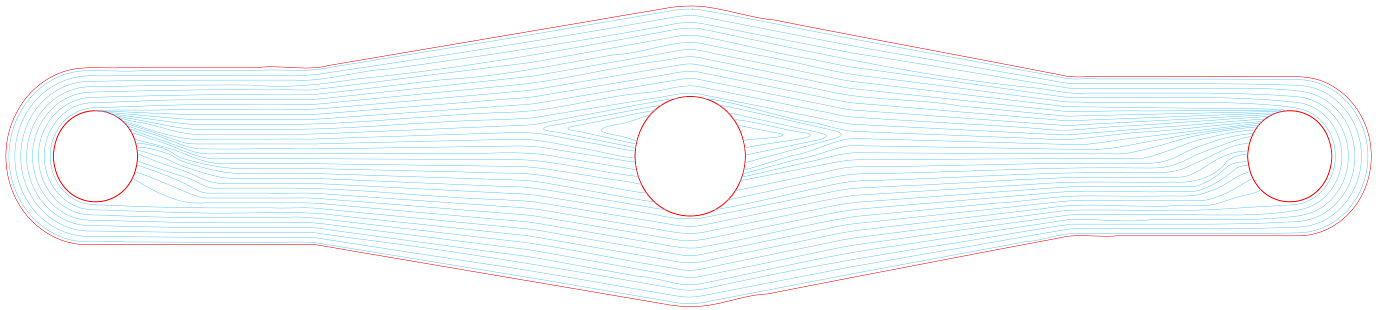
Load cases



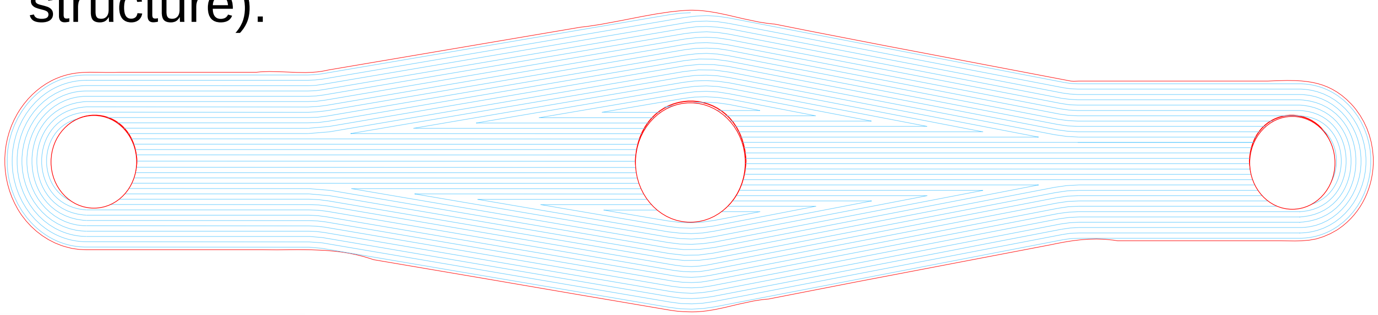
	Load case 1 Tension	Load case 2 Tension / Compression	Load case 3 Bending
Eye 1	0.94 P	P	Fixed
Eye 2	Fixed	Fixed	0.81 P
Eye 3	0.85 P	0.85 P	Fixed
P: Reference load			

Rovings of the Optimized HTP Connection Beam

Optimised for the combined load cases *bending* and *tension* (not recommended):



Optimised for the load case *tension* (manufactured for the test structure):



Results – Expected Maximum Loads

Load case		Load case 2		Load case 3
	Load case 1			
	Tension (Eye 1)	Tension (Eye 3)	Compression (Eye 1)	Bending (Eye 2)
Simulation: Failure mode / Layer	FF (±45°-layer)	FF (±45°-layer)	IFF (0°-layer)	FF (0°-layer)
Simulation: Optimized HTP connection beam (**best known** TFP material strengths)	Maximum load at first ply failure			
	2.09P	1.88P	2.65P	1.03P
Experi-ment: Conventional HTP connection beam	Maximum test load			
	0.94P	0.85P	P	0.81P
Expected improvement in %	122.3	121.2	165	27.1

Results – Test results

Load case			Load case 2		Load case 3
		Load case 1			
		Tension (Eye 1)	Tension (Eye 3)	Compression (Eye 1)	Bending (Eye 2)
Simu-lation	Optimized HTP connection beam (**realized** TFP material properties)	Maximum load at first ply failure			
		1.60P	1.41P	1.78P	0.75P
Experi-ment	Optimized HTP connection beam	Maximum test load			
		1.51P	1.36P	1.79P	0.75P
	Conventional HTP connection beam	0.94P	0.85P	P	0.81P
Improvement in %		61	60	79	-8

significant improvement!

Publication:

Rolfes R., Tessmer J., Degenhardt R., Temmen H., Bürmann P., Juhasz J., *"New Design Tools for Lightweight Aerospace Structures", Proceedings of the Seventh International Conference on Computational Structures Technology, Lisbon, Portugal, 7-9 September, 2004*

Overview projects on TFP

Project 2 **KRAFT**
(2003-2007)
Funding: Lufo III
TFP-Basic research investigations

→

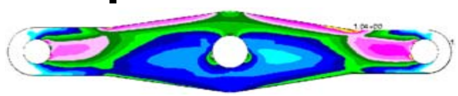
Project 3 **EMIR**
(2003-2006)
Funding: Lufo III
Automatic TFP-Algorithm (TACO)

→

Project 4 **ROVING**
(2003-2006)
Funding: Lufo IIb and Germany
Automatic Determination of the roving distribution

↑ ↑ ↑

Project 1 **Design fundamentals for 3D reinforced composites**
(2000-2003)
Funding: German state Lower Saxony and Airbus Germany

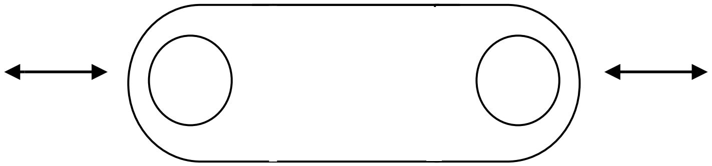


TFP-Design tool TACO (not automated) and application on the HTP-connection beam

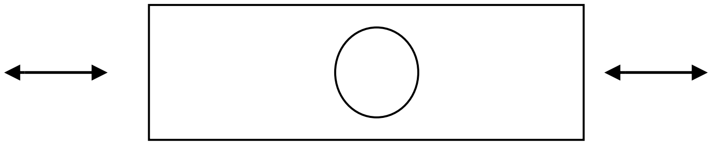
Objectives

- Improved estimation of the load carrying capacity of composite structures made in TFP
- TFP design rules
- Investigation of different optimization strategies
- Improved load introduction (e.g. non-linear computation)
- Experimental investigations for the validation of the simulations

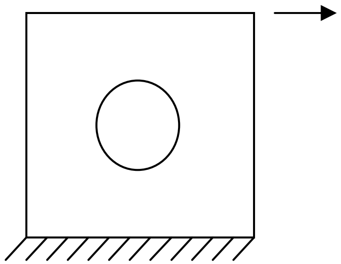
Investigated structures



Structure A: Two loaded holes



Structure B: One open hole

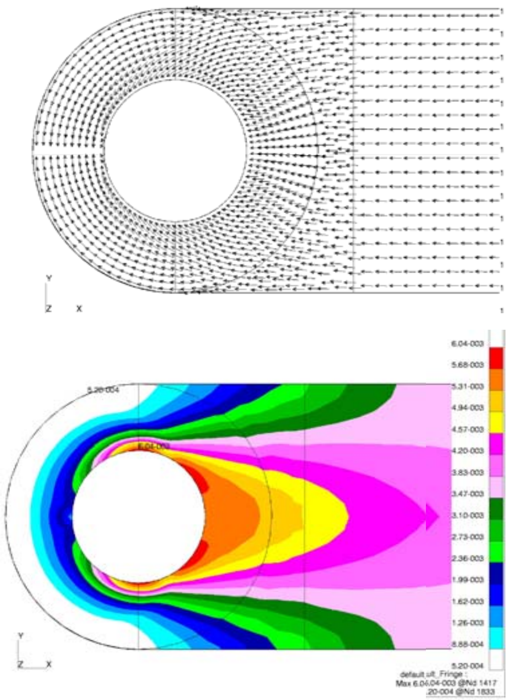


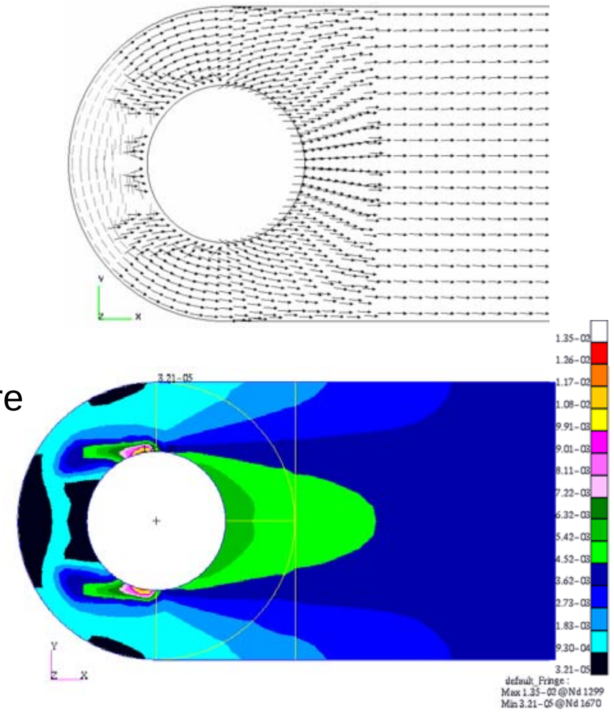
Structure C: Shear plate with an open hole

Optimisation strategies

Optimisation according to the signum of principle stresses

Optimisation according to the absolute value of principle stresses





Inter Fibre Fracture (IFF)

IFF=0,00604 FF=0,00591

material effort

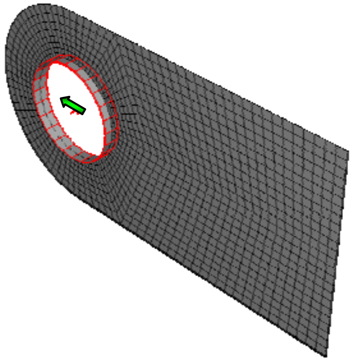
IFF= 0,0135 FF= 0,0058

Mattheck - CAIO

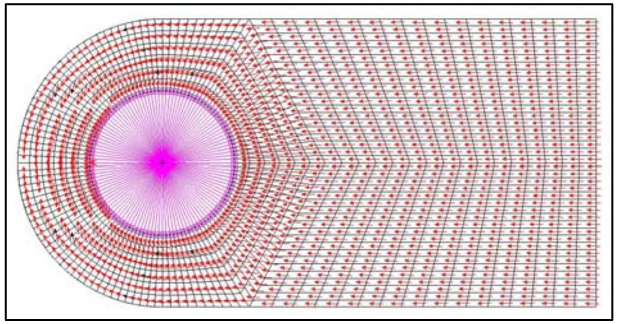
Tosh / Kelly - Load paths method

Load introduction

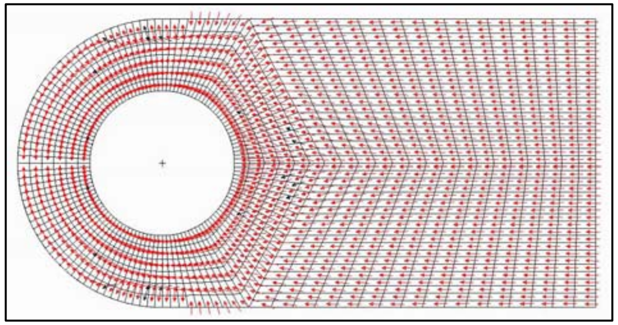
Contact model



Optimisation using MPC

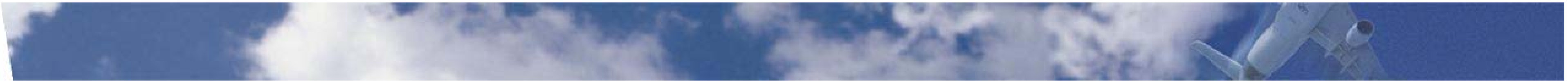


Optimisation considering contact

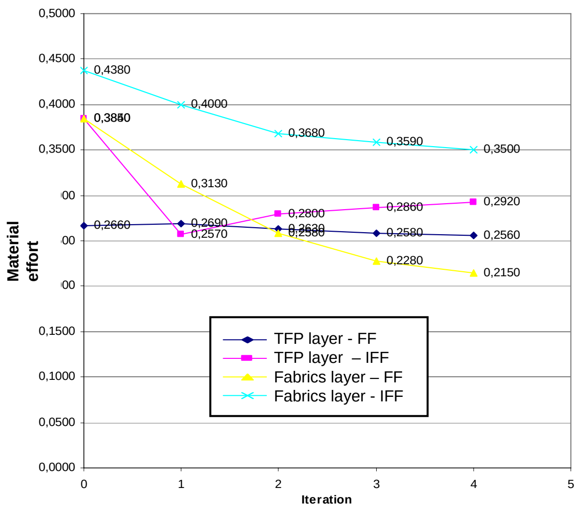


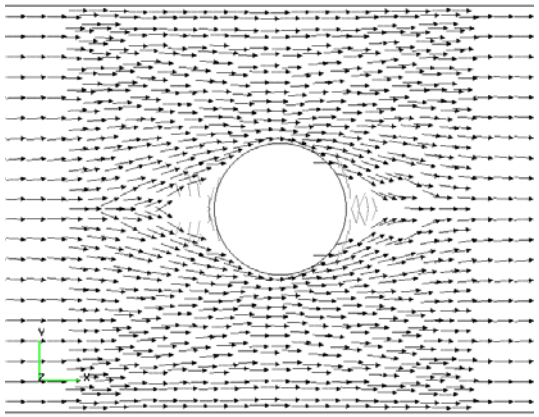
Results:

- Strategy for the modelling of the contact problem
- Improved understanding of the load introduction in the contact region
- Basis for follow-up investigations



Investigation of structure B under tension

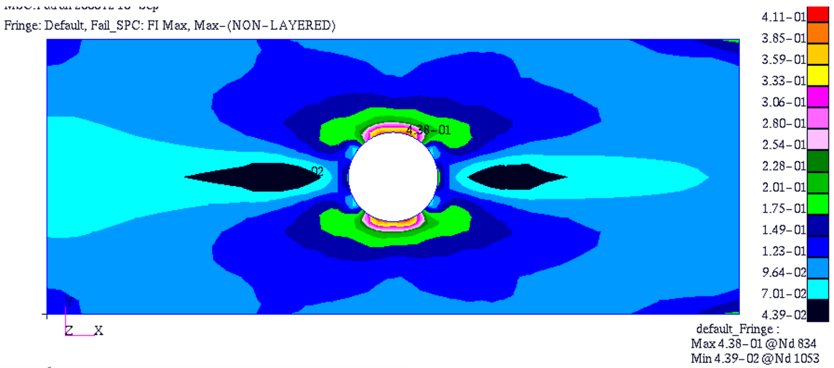




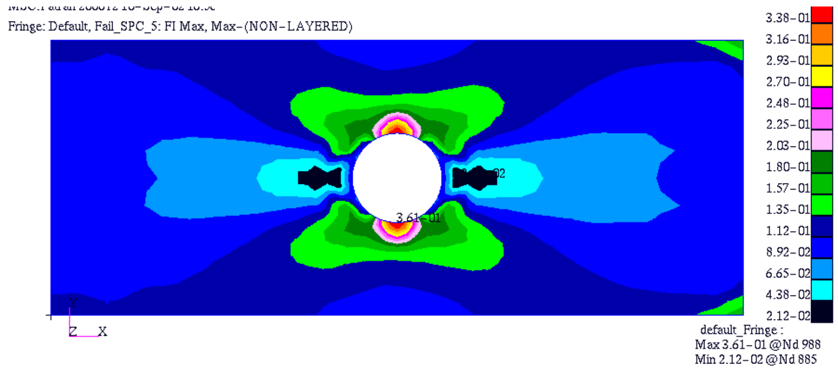
- The load carrying capacity could be improved by 25%
- Roving distance and therefore structure thickness not constant

Material efforts

before optimisation

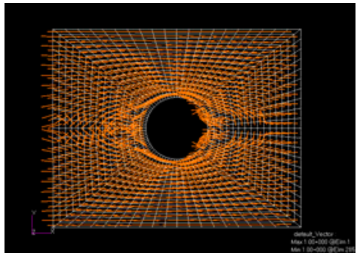


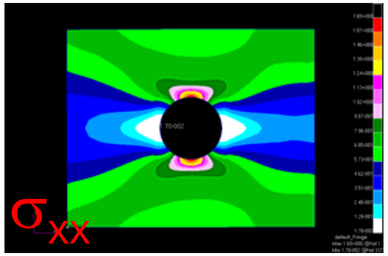
after optimisation



Producible roving distributions

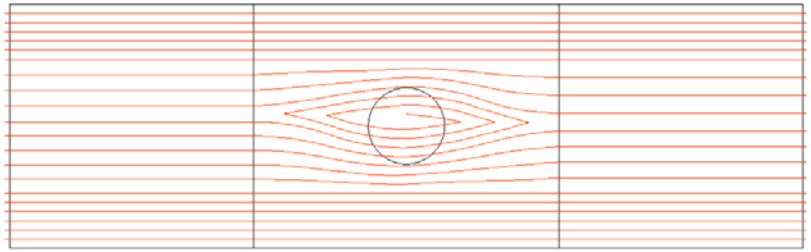
Two Concepts of roving distributions are realised for experimental investigation of structure B

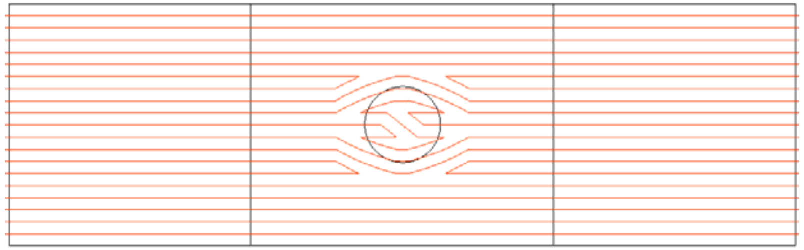




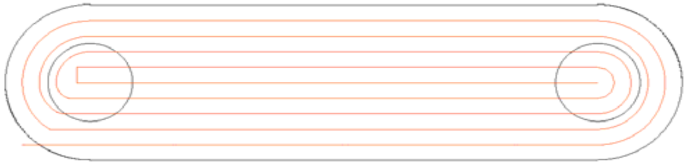
Structure B variable fibre volume fraction (non constant thickness)

Structure B constant fibre volume fraction



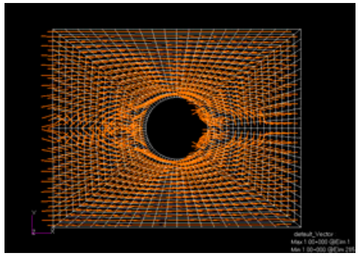


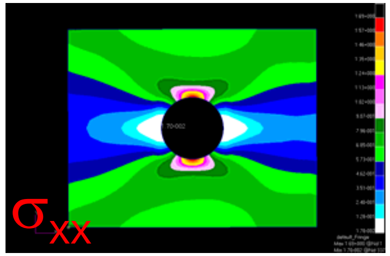
Structure A



Producible roving distributions

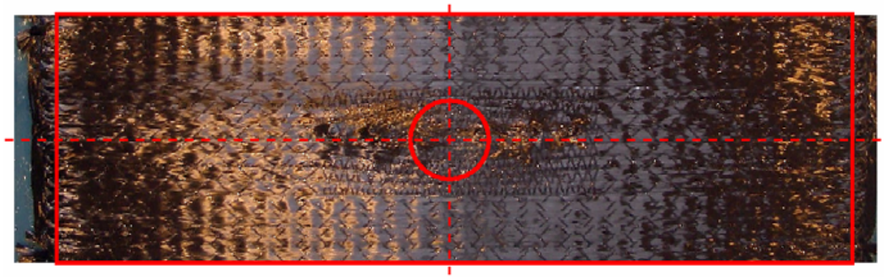
Two Concepts of roving distributions are realised for experimental investigation of structure B

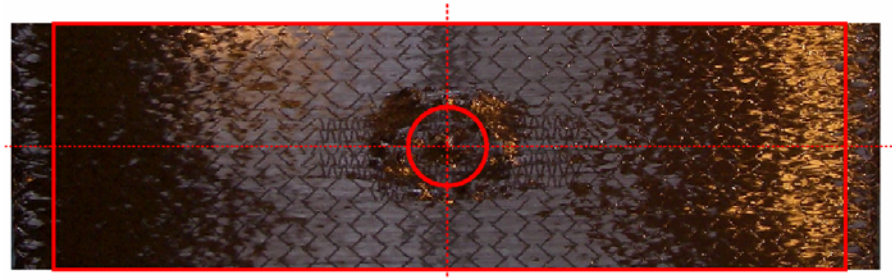




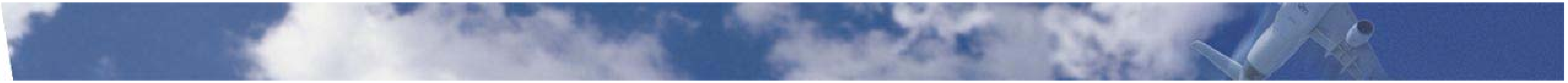
Structure B variable fibre volume fraction (non constant thickness)

Structure B constant fibre volume fraction



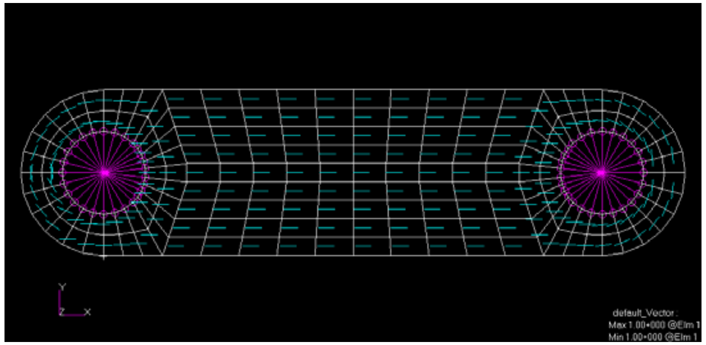


Structure A



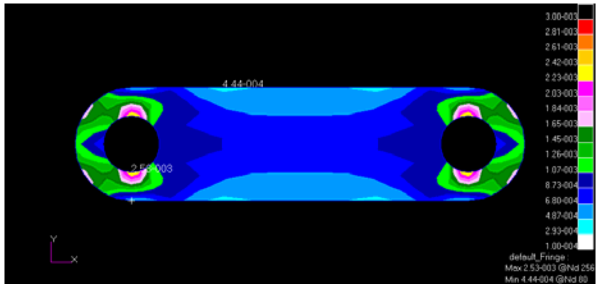
Analysis of manufactured roving distributions

Feedback of manufactured roving distributions to FE-models (secondary models)

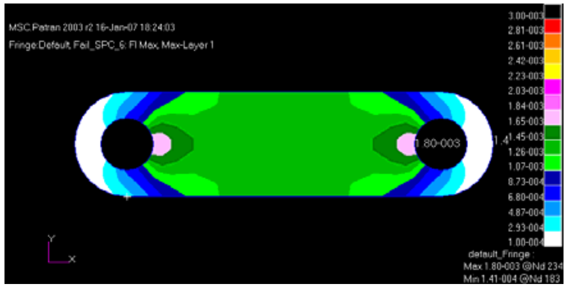


- 'Feedback'-models show locally raised material effort
- Quantification and evaluation of the effects of local degradation is subject of future work

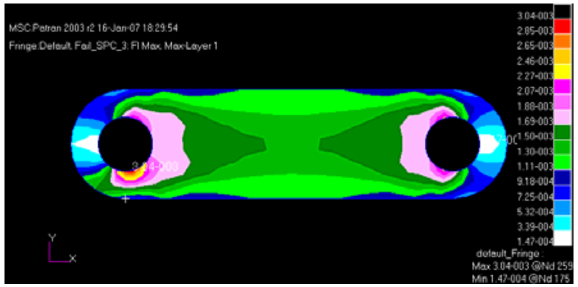
Maximum effort over all layers



Initial state



Optimised solution



'Feedback'-model

Summary and Conclusions

- Introduction to TFP Technology
- Projects on TFP
  EMIR, KRAFT
- Computation, optimisation
  TFP optimisation tool TACO
- Application of TACO on a structural Component
  HTP connection beam
- Selected results of recent research, basic investigations
  - Optimisation strategies
  - Load introduction, optimisation considering contact
  - Feedback of manufactured roving distributions

- TFP promises significant weight reduction for structures which are subjected to a limited number of load cases