dynardo | presented at the 3rd Weimar Optimization and Stochastic Days 2006
Source: www.dynardo.de/en/library

Optimization of Laminated Structures

Weimarer Optimierungs- und Stochastiktage 3.0

EVEN – Evolutionary Engineering AG
Technoparkstr. 1
CH-8005 Zurich
Switzerland

Phone : +41 (0) 44 500 93 60
Fax : +41 (0) 44 500 93 61
Mail: info@even-ag.ch
WWW: www.even-ag.ch

Contents

- EVEN – Evolutionary Engineering AG
- Introduction to laminated structures
- Two different approaches to describe a laminated structure
- Parameterization of a laminate based on laminate regions
- Parameterization of a laminate based on pieces of reinforcement fabric
- Conclusion and questions

EVEN – Evolutionary Engineering AG

- Spin-off company of the Swiss Federal Institute of Technology Zurich
- Proprietors:

O. König	Dr. sc. techn.
M. Wintermantel	Dr. sc. nat.
N. Zehnder	Dipl. Masch.Ing. ETH

- Foundation: January 28 2004
- Location: Zurich, Switzerland

Core competencies

- Optimization of mechanical structures
- Structural analysis of mechanical structures using FEM
- Structural design of mechanical structures
- CAD technology
- Engineering software development

PARTNERS:

dynardo

TRANSCAT
A Dassault Systemes Company

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Contents

- EVEN – Evolutionary Engineering AG
- Introduction to laminated structures
- Two different approaches to describe a laminated structure
- Parameterization of a laminate based on laminate regions
- Parameterization of a laminate based on pieces of reinforcement fabric
- Conclusion and questions

Introduction to laminated structures

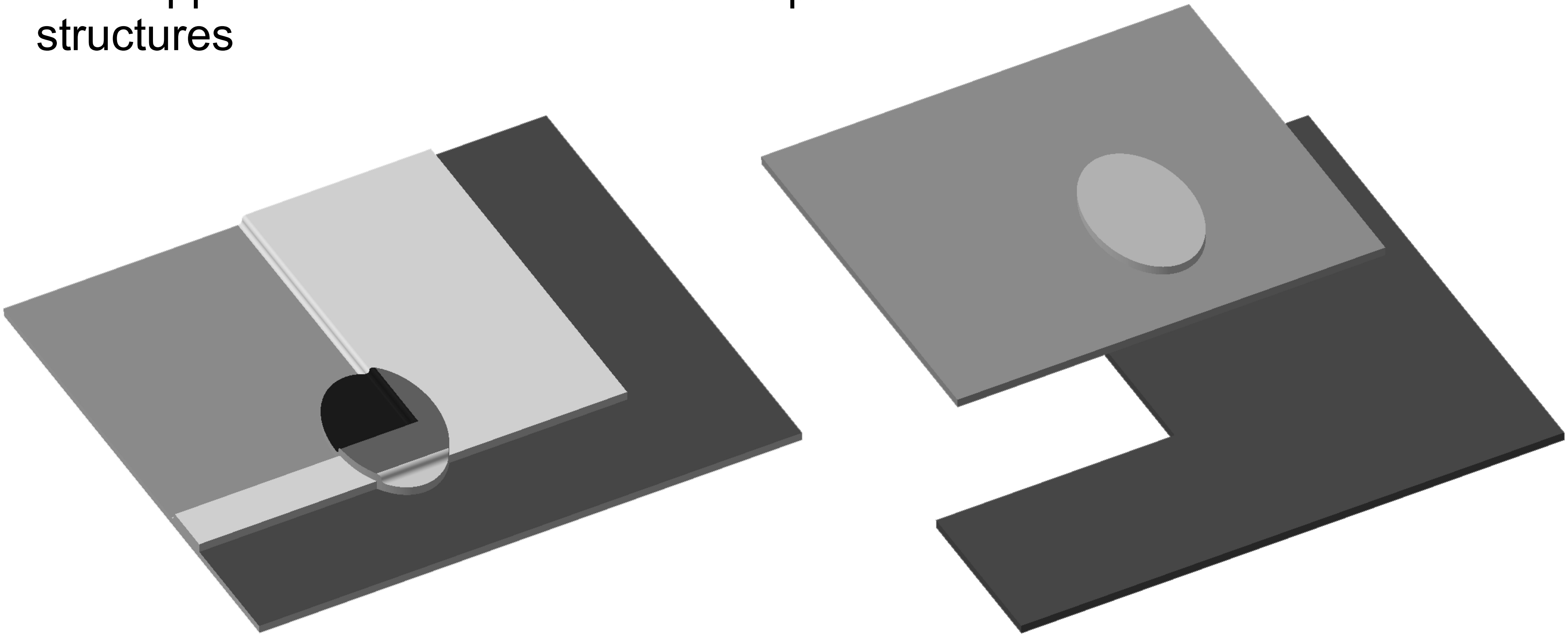
- Laminated structures are built from multiple layers of fiber reinforced plastics
- Each layer consists of reinforcement fibers which are embedded in a plastic matrix
- For economic reasons the reinforcement fibers are often pre-manufactured in a textile form
- A complex structure is built through the consecutive placement of reinforcement fibers in a mold
- The local material properties are given by the amount, orientation, and the stacking sequence of the present layers
- **The local material properties are design parameters**
- **This increases the amount of design parameters and makes numerical optimization a natural tool for the designer of laminated structures**

Contents

- EVEN – Evolutionary Engineering AG
- Introduction to laminated structures
- Two different approaches to describe a laminated structure
- Parameterization of a laminate based on laminate regions
- Parameterization of a laminate based on pieces of reinforcement fabric
- Conclusion and questions

Two different approaches to describe a laminated structure

- The classical engineering (simulation) approach is based on laminate regions
- The workshop approaches a laminated structure the way it is built: By successive placement of pieces of reinforcement fibers in the mold
- Both approaches can be used for the parameterization of laminated structures



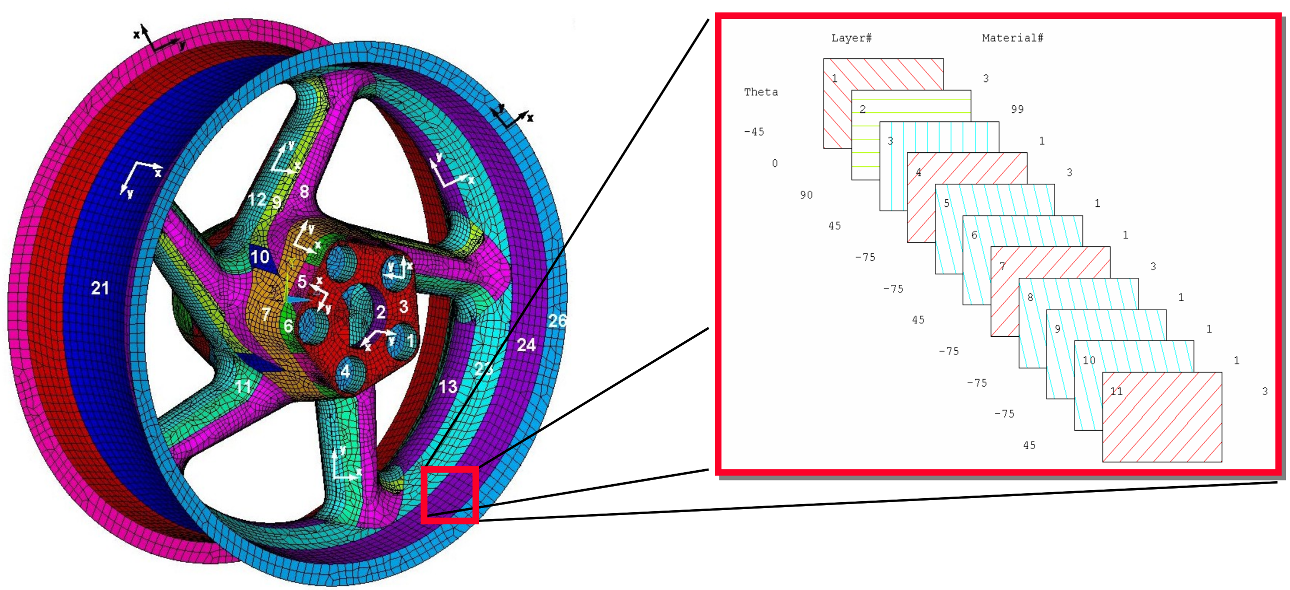
Contents

- EVEN – Evolutionary Engineering AG
- Introduction to laminated structures
- Two different approaches to describe a laminated structure
- Parameterization of a laminate based on laminate regions
- Parameterization of a laminate based on pieces of reinforcement fabric
- Conclusion and questions

Parameterization of a laminate based on laminate regions I

CFRP motorcycle rim: Parameterization

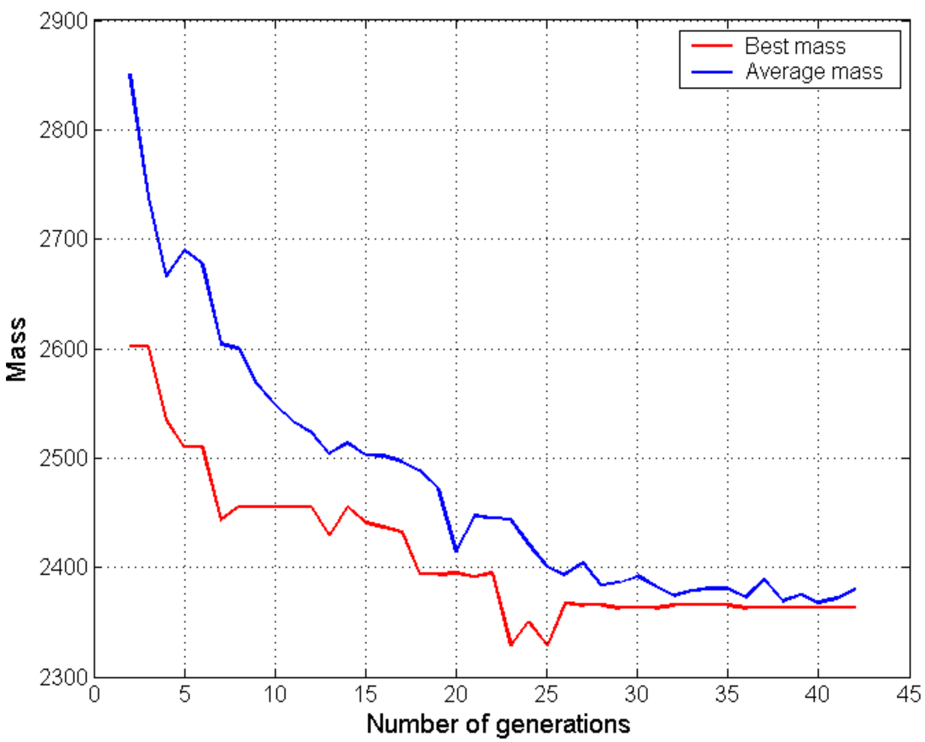
- Laminate regions are fixed, mostly based on engineering intuition
- In every laminate region the amount of layers, their materials, their orientation, and their stacking sequence are design parameters
- Inherently there is no connection between laminate regions and often additional parameter linking is required
- The parameterized optimization model can be set up as a finite element model

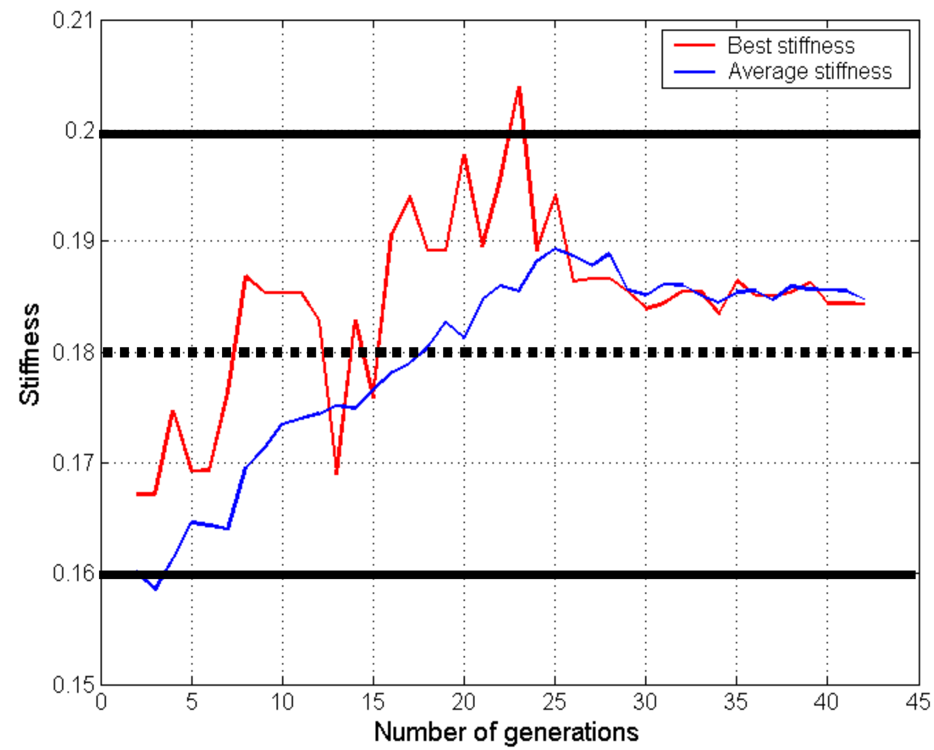


Parameterization of a laminate based on laminate regions II

CFRP motorcycle rim: Optimization

- Convergence plots for an evolutionary optimization with 50 individuals over 42 generations
- The mechanical properties of the CFRP rim are adjusted to be similar to a state of the art magnesium rim





Parameterization of a laminate based on laminate regions III

CFRP motorcycle rim: Results

- The resulting rim weighs 2250g which is about 25% less than a Mg rim

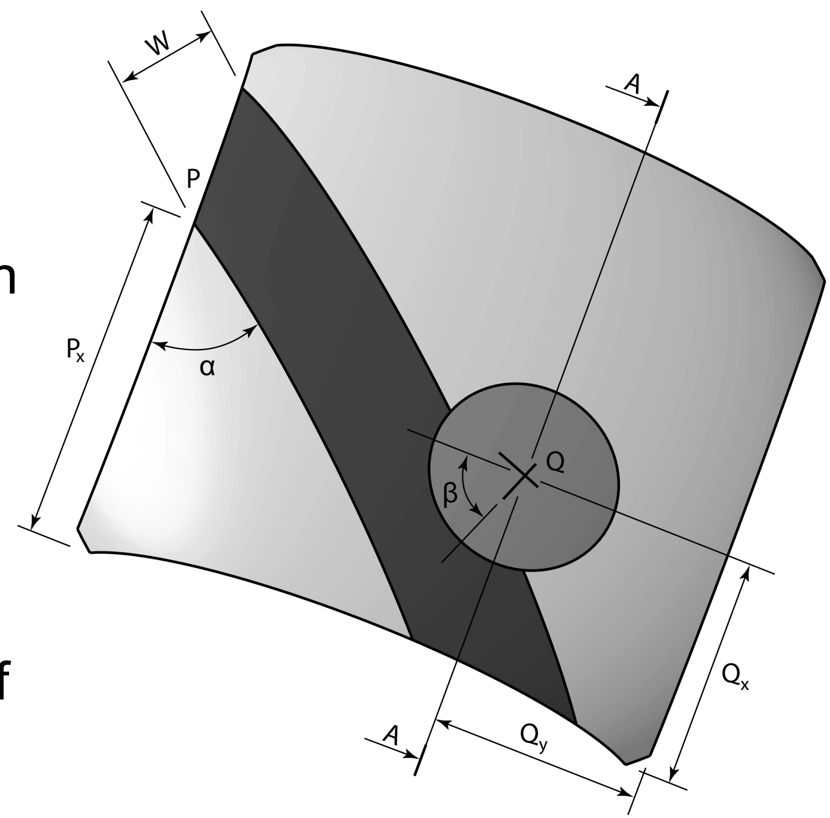
Contents

- EVEN – Evolutionary Engineering AG
- Introduction to laminated structures
- Two different approaches to describe a laminated structure
- Parameterization of a laminate based on laminate regions
- Parameterization of a laminate based on pieces of reinforcement fabric
- Conclusion and questions

Parameterization of a laminate based on laminate regions IV

Discussion

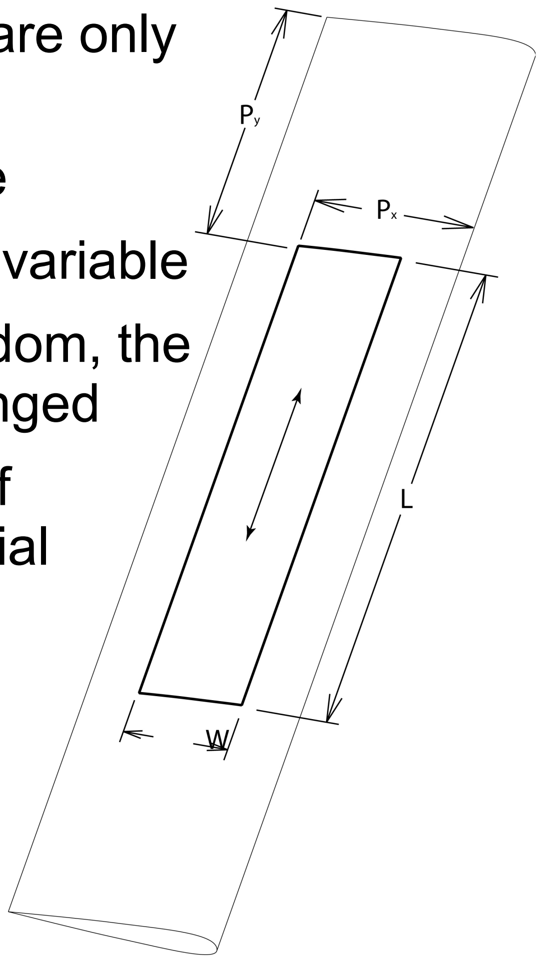
- Within the given parameterization a good solution is found, but:
  - Could a variation of the laminate region lead to a more efficient design?
- Using the finite element model for the parameterization does not allow the variation of laminate regions or it is mesh dependent
- Using a CAD tool to define the lamination plan allows to change the geometrical definition of the different regions
- Furthermore the regions are not defined as laminate regions, but as the areas a piece of reinforcement fiber covers on the structure

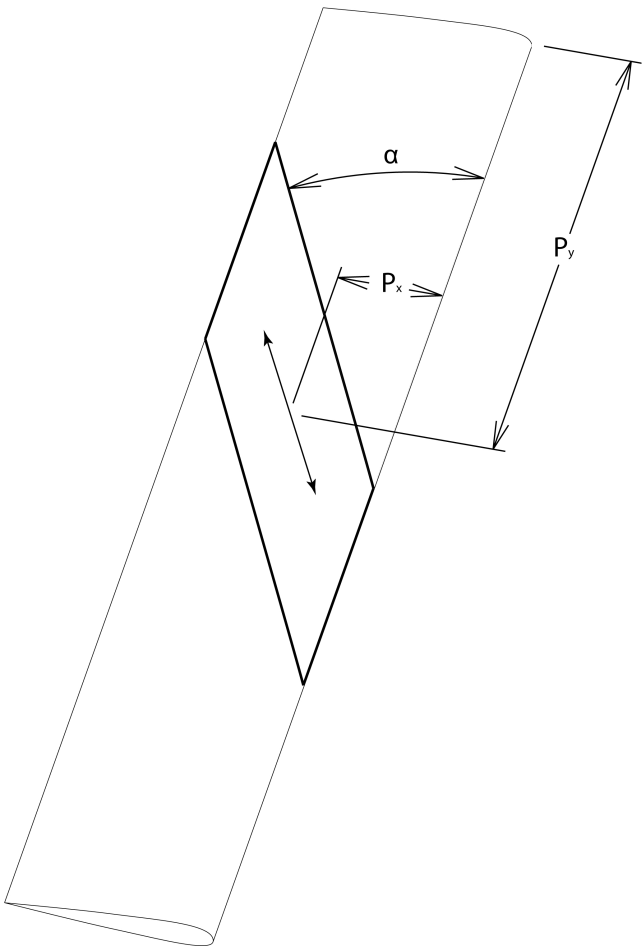


Parameterization of a laminate based on pieces of reinforcement fabric I

Parameterization

- The structure is a keel fin of a sailing boat
- To minimize waste, the pieces are only rectangular
- The width and length is variable
- The position on the structure is variable
- As an additional degree of freedom, the angle of the pieces can be changed
- For every area a combination of unidirectional and weave material can be applied
- For each material the individual thickness can be chosen





Parameterization of a laminate based on pieces of reinforcement fabric II

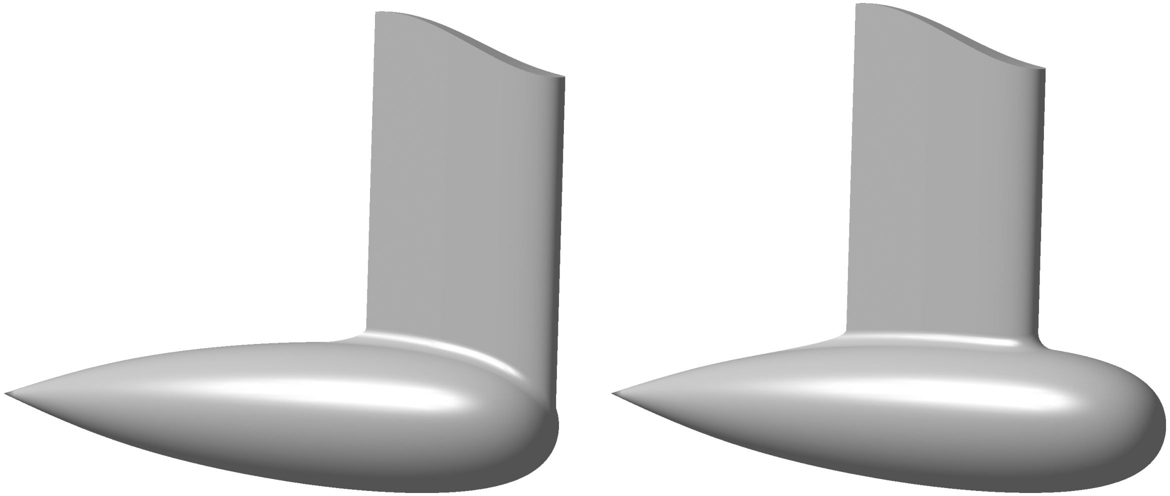
Problem description I

- Design the keel fin of a sailing boat
- The keel is assumed to be canted at an angle of 40º
- The boat is healed by 14º resulting in an overall angle of 54º
- The bulb has a mass of 3 tons
- Minimize the twisting angle at the fin's tip for a given mass and a given bending deflection

Parameterization of a laminate based on pieces of reinforcement fabric III

Problem description II

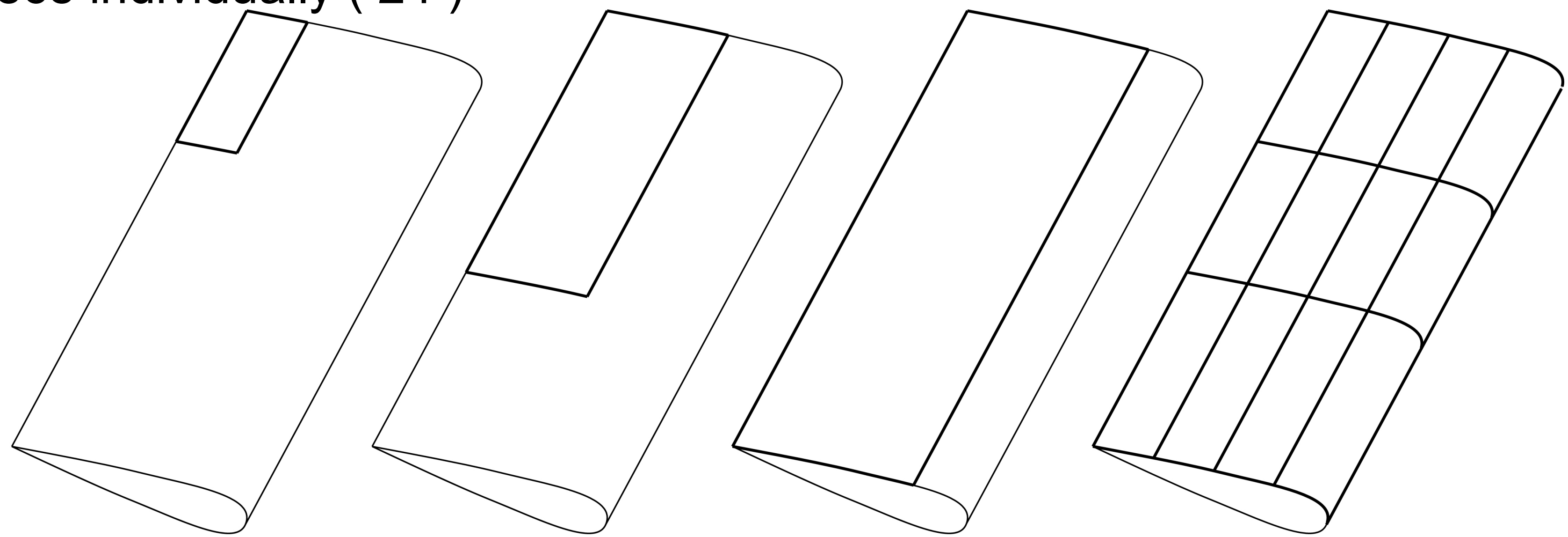
- When canted, the keel fin of a sailing boat can be loaded with torsional loads due to a trailing bulb
- This torsional moment twists the fin in a way that reduces the righting moment and is therefore unwanted
- The goal is to minimize the twist using a laminated keel fin
- Three different parameterization schemes are applied and compared



Parameterization of a laminate based on pieces of reinforcement fabric IV

Parameterization I

- Fixed parameterization
- The pieces of reinforcement fabric are not allowed to move
- Every area can be covered with unidirectional and woven material
- Every piece starts at the trailing edge in order to move the shear center of the cross sections backwards
- The optimization parameters are the thicknesses for both materials of every piece individually (24)



Parameterization of a laminate based on pieces of reinforcement fabric V

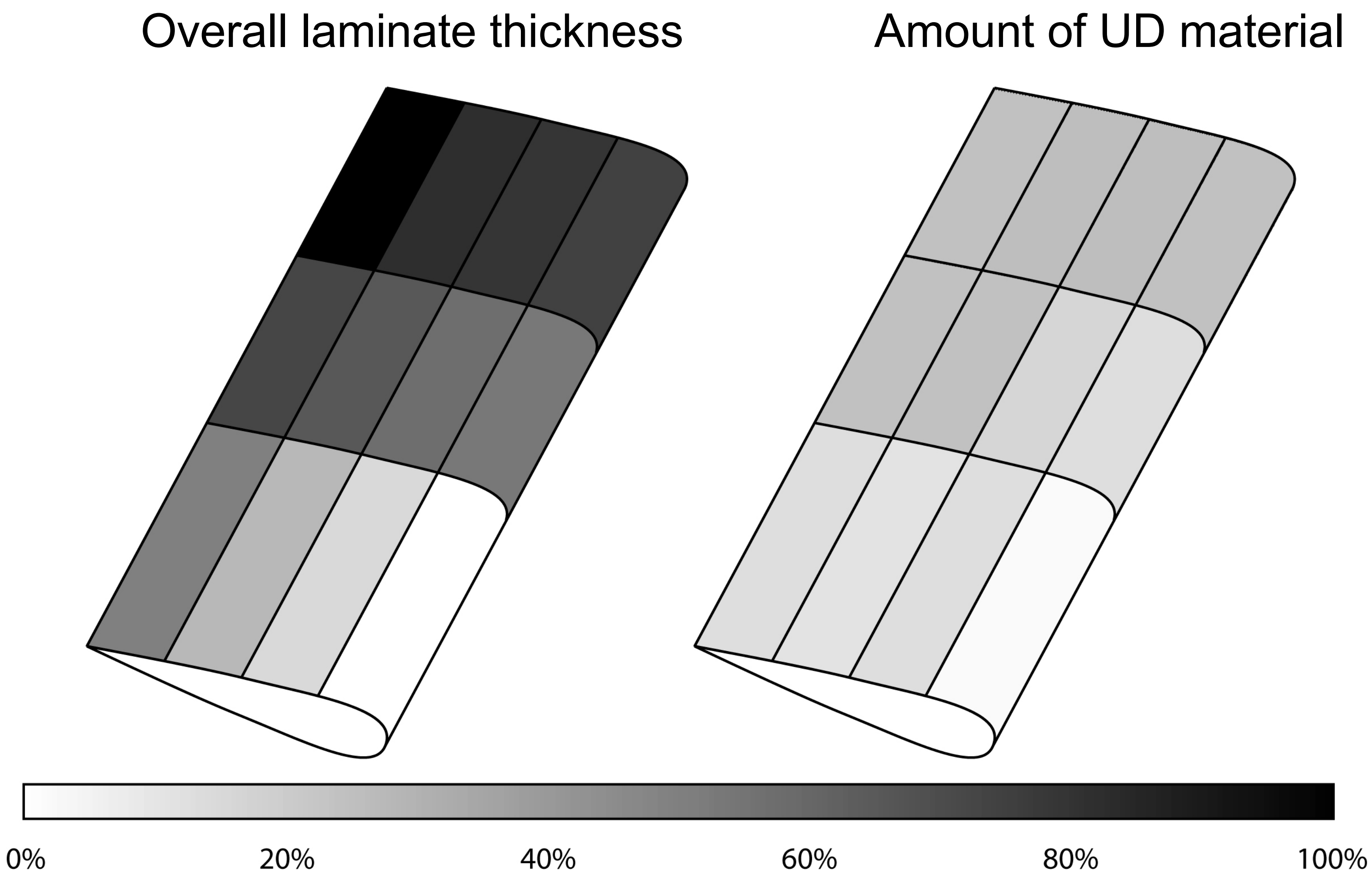
Parameterization II

- Geometrically variable without angles
- The pieces of reinforcement fabric are not allowed to move, but they are constrained to the root and the trailing edge
- The optimization parameters are the thicknesses, the lengths, and the widths of every piece individually (24 thicknesses + 11 lengths + 11 widths = 46)

- Geometrically variable with angles
- In addition to the above there are parameterization, 10 unidirectional pieces are added which are allowed to change their angle, width, length, and thickness (76)

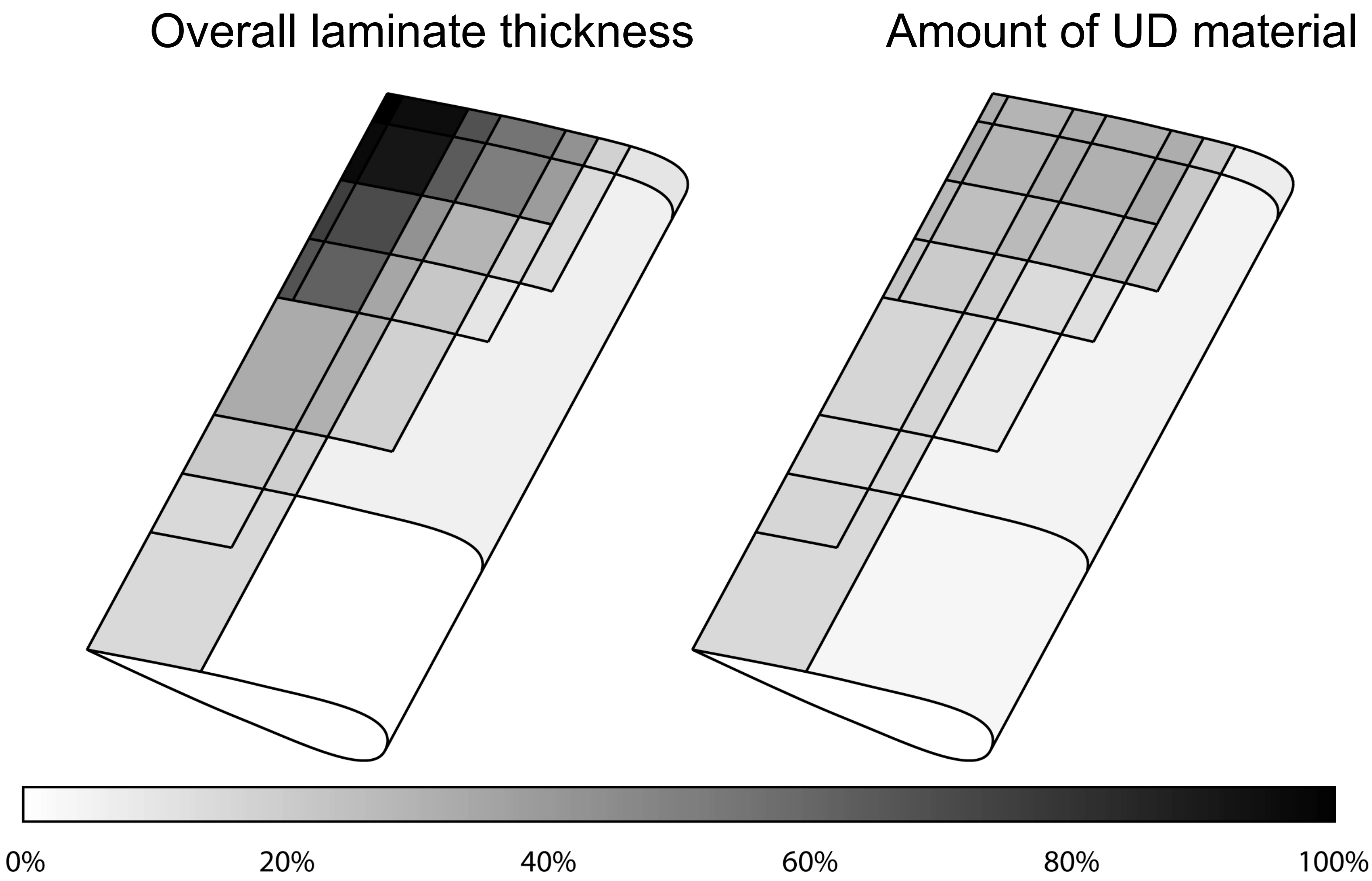
Parameterization of a laminate based on pieces of reinforcement fabric VI

Results I



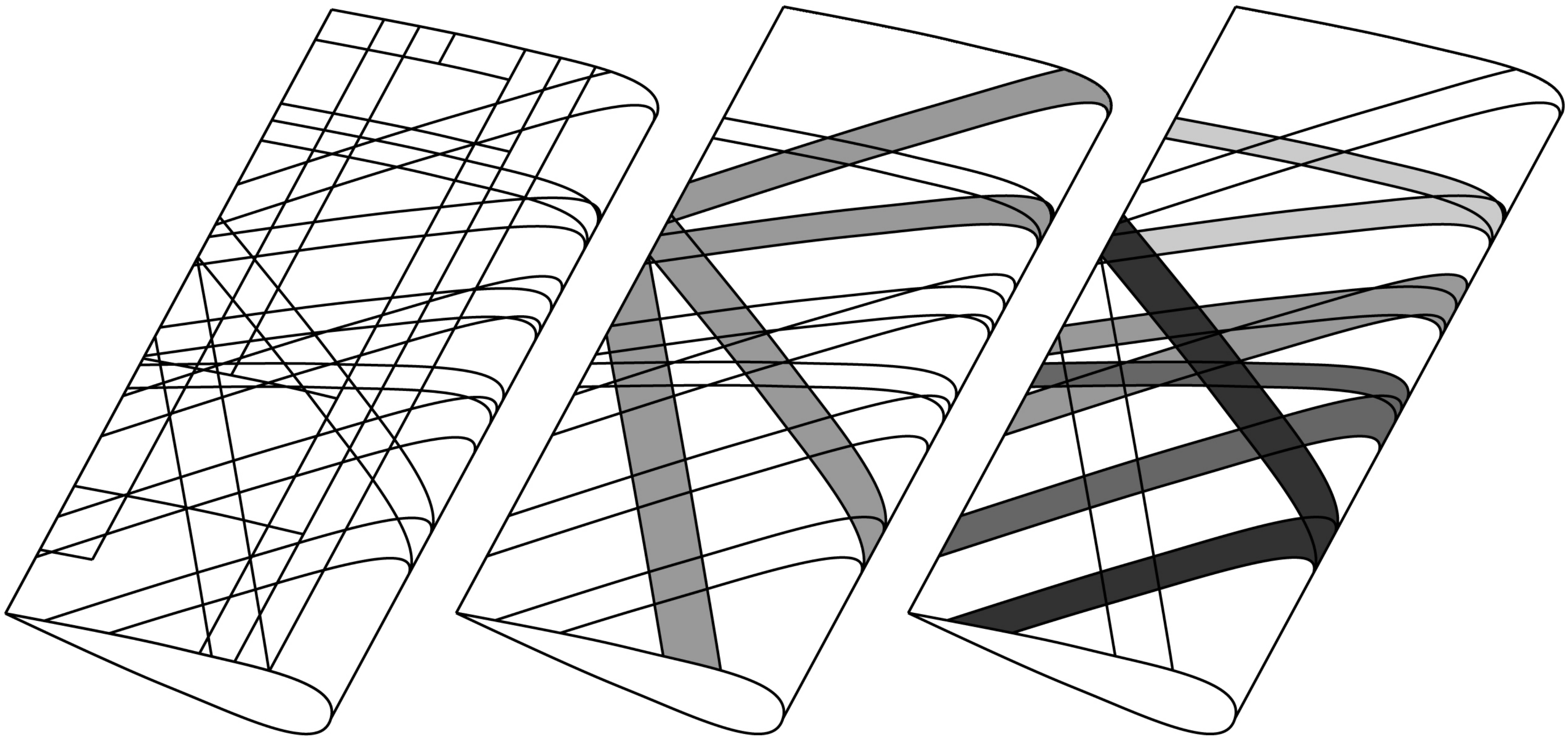
Parameterization of a laminate based on pieces of reinforcement fabric VII

Results II



Parameterization of a laminate based on pieces of reinforcement fabric VIII

Results III



Parameterization of a laminate based on pieces of reinforcement fabric IX

Results VI

- Comparison of the numeric results
- The reference fin has a uniform thickness distribution
- The comparison of the twist shows a decrease for growing amount of flexibility in the laminate design
- The tip deflection is coupled to the twist but:
- It is seen that the angular parameterization allows a separation of the deflection and the twist

	reference	fixed	longitudinal	angular
# parameters	0	24	46	76
mass	100%	103%	102%	98%
deflection	100%	81%	74%	81%
twist	100%	91%	86%	43%

Conclusion

- Two different approaches to the parameterization of laminates has been shown: One relies on the FE model only, the other requires the use of an associative parametric CAD system
- The FE model based approach is restricted to laminate optimization in previously defined regions
- The CAD based approach allows the laminate regions to move and to form itself, since the laminate is regarded as the assembly of the layers

- **The possibility to move the laminate regions delivers additional optimization parameters which are important in the search for better solutions**