Laminate optimization capabilities applied to a racing car monocoque

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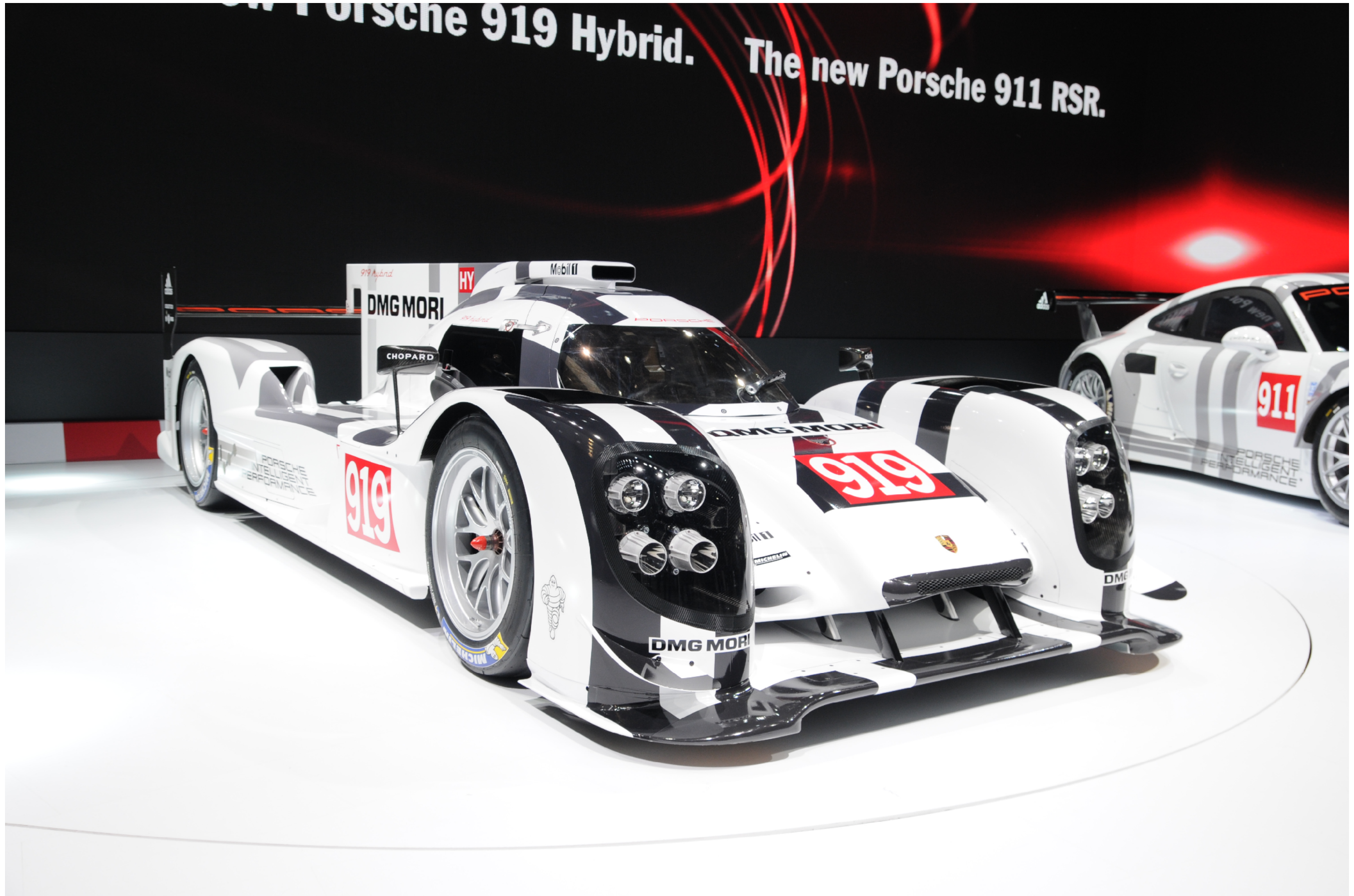
Introduction

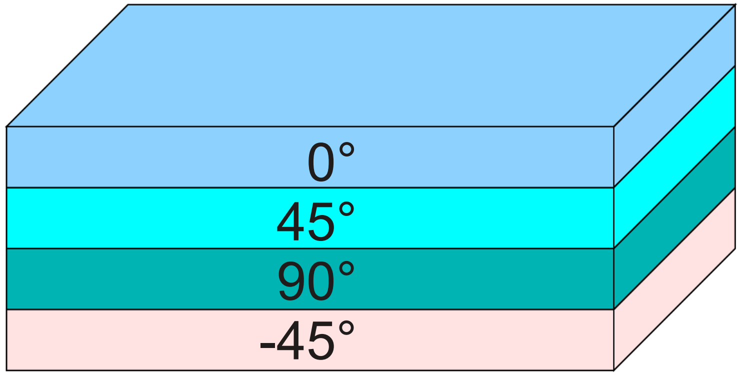
- New application of optimization in PERMAS V17
- Development project initiated by Porsche Motorsport
- Two different phases of optimization:
  - STEP1: Optimization of ply *shapes*
  - STEP2: Optimization of ply *stacks*

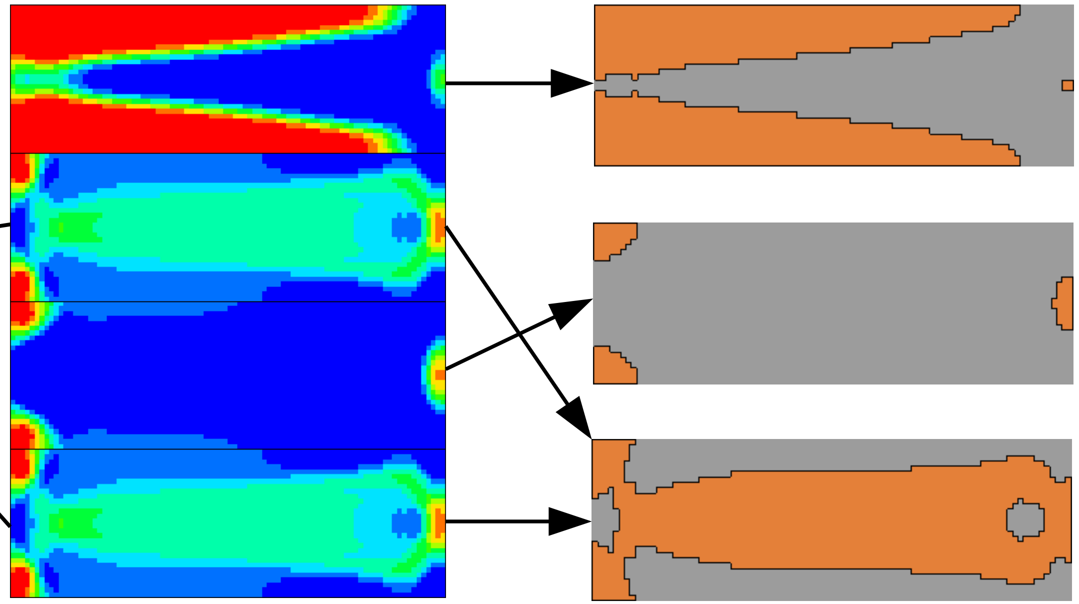


Source: Wikipedia

STEP1: Optimization of ply shapes

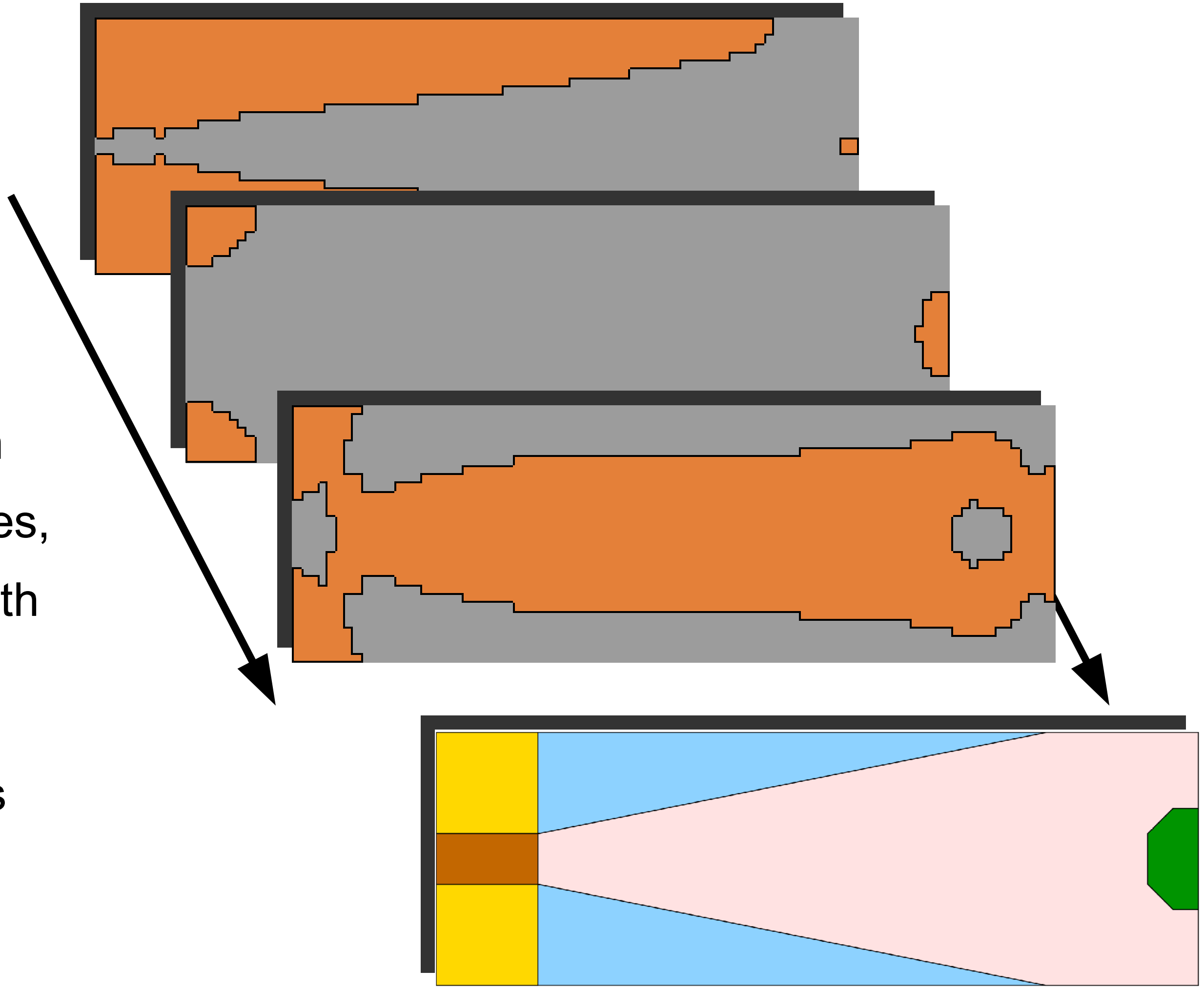
- 'Super-Ply-Elements': Total thickness of plies with a specific orientation of fiber angles for *each element as* design variables
- *'Freesize' optimization* similar to topology optimization, i.e. find new design concepts
- *'Freesize'* optimization new option in PERMAS V16, extended for laminates in V17
- Basic manufacturing constraints, eg. balancing ±45° or total thickness of each 'Super-Ply'
- Using optimized thickness distributions of 'super-plies' for the generation of ply shapes as element sets





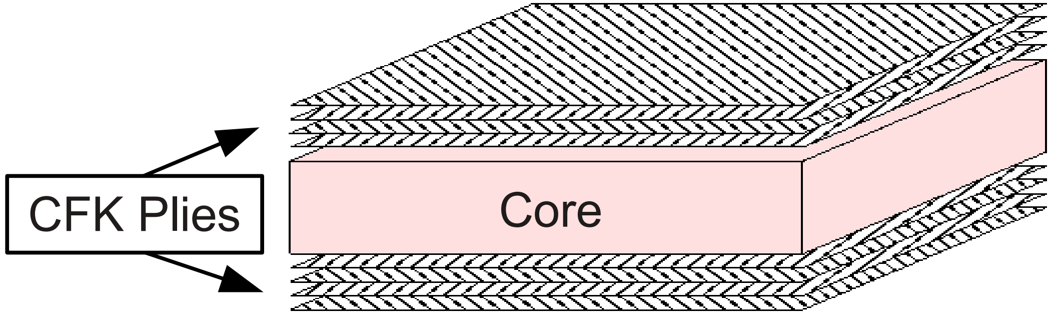
STEP2: Optimization of ply stacks

- Ply shapes of STEP1 as input for creation of new laminates (= ply stacks)
- Simplification and manufacturing considerations using engineering experience!
- Ply thicknesses (i.e. nr. of plies) and/or orientation angles of pre-defined laminates as design variables, hence reducing to 'classical' *sizing optimization* with moderate number of variables
- Incorporation of detailed manufacturing conditions and additional constraints e.g. ply failure criteria



5 ply stacks (=laminates) from simplified ply shapes

Monocoque model



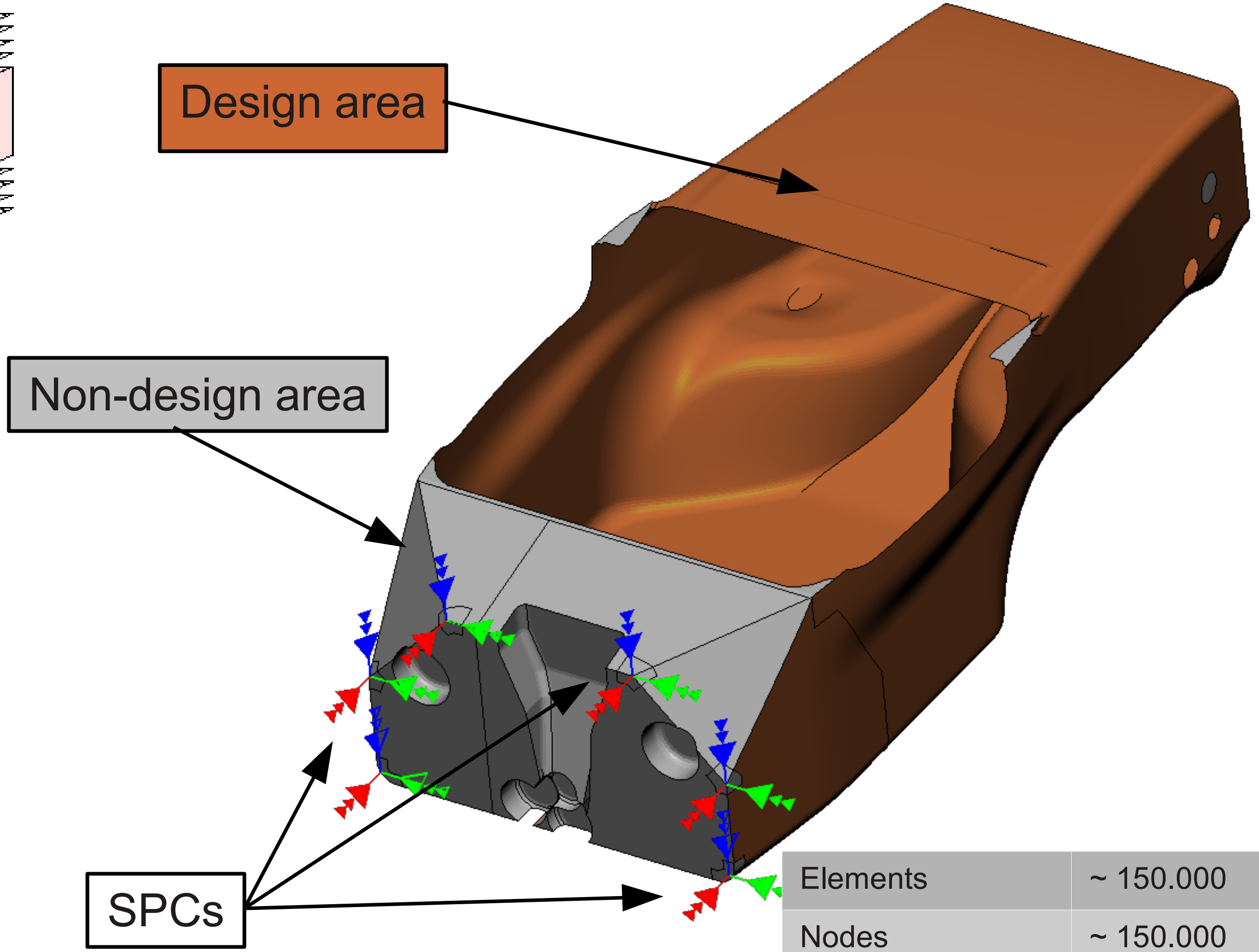
- Laminates with core (unchanged) and several CFK plies on both sides:

  Core thickness : ∑ Ply thickness ~ 10 : 1

  Core weight : ∑Ply weight ~ 1 : 2

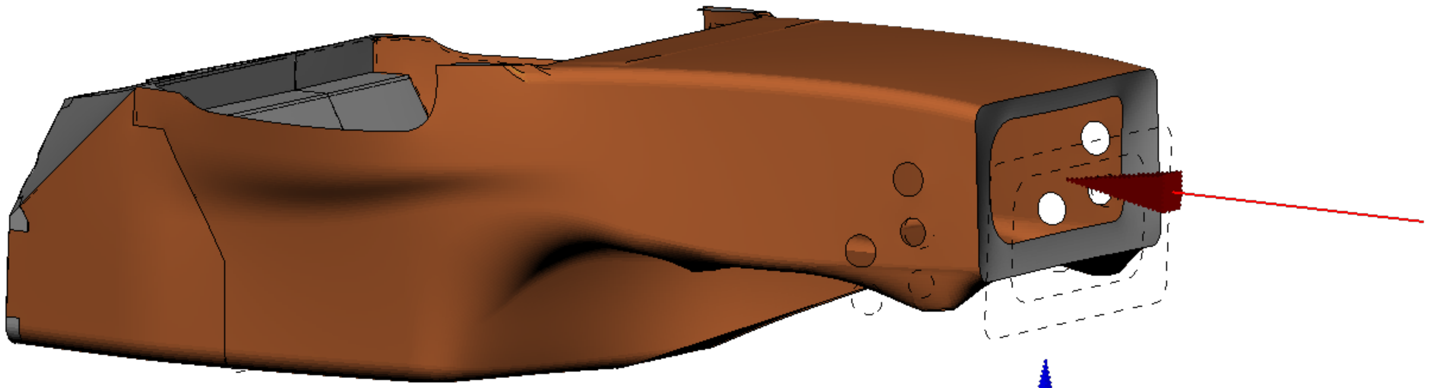
- Design area ~ 75% (~ 110.000 Elements)
  - Weight of 'Designed Plies' ~ 50%

- 4 static load cases: Forces and a moment applied at the rear end (see next page)

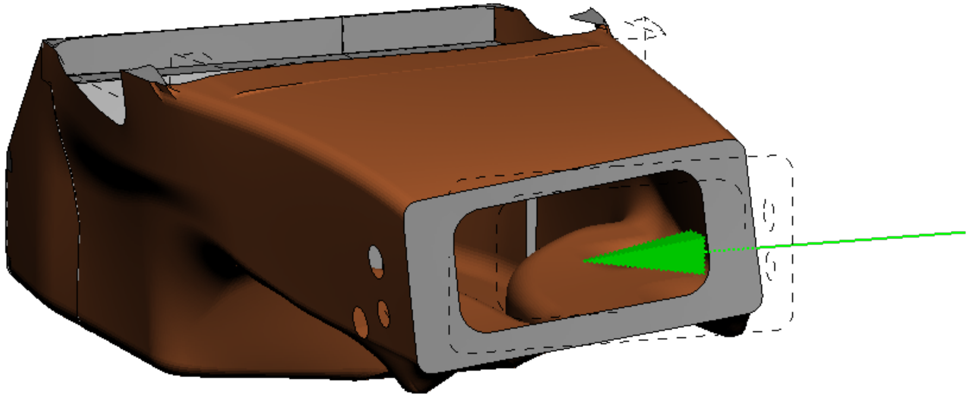


Elements	~ 150.000
Nodes	~ 150.000
Unknown DOFs	~ 900.000

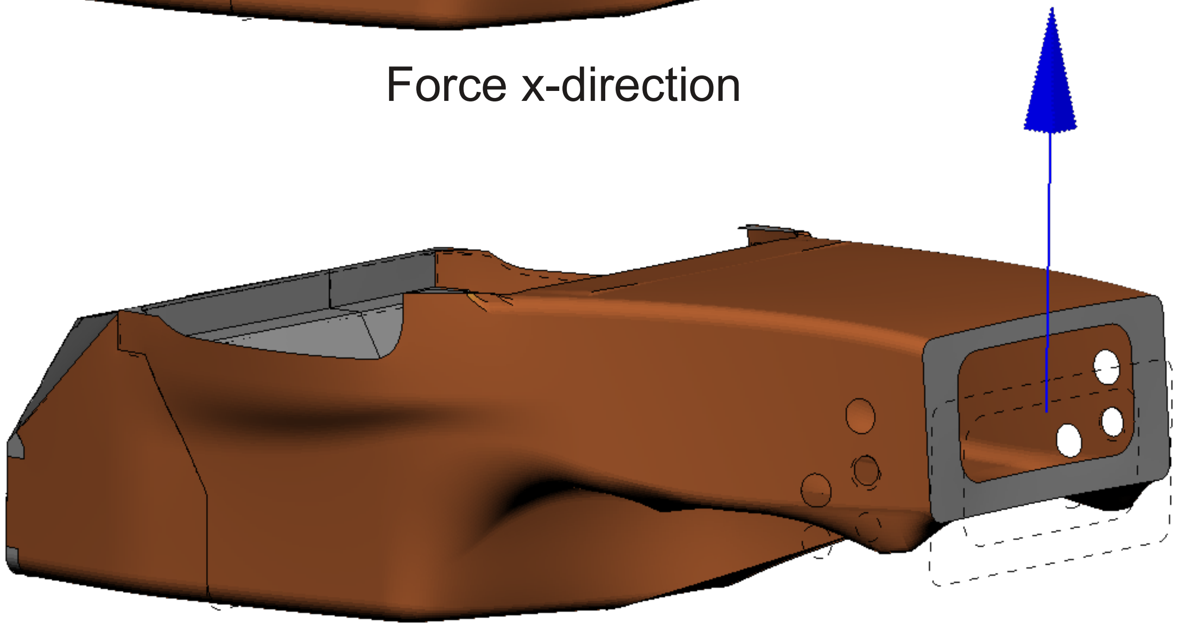
Load cases



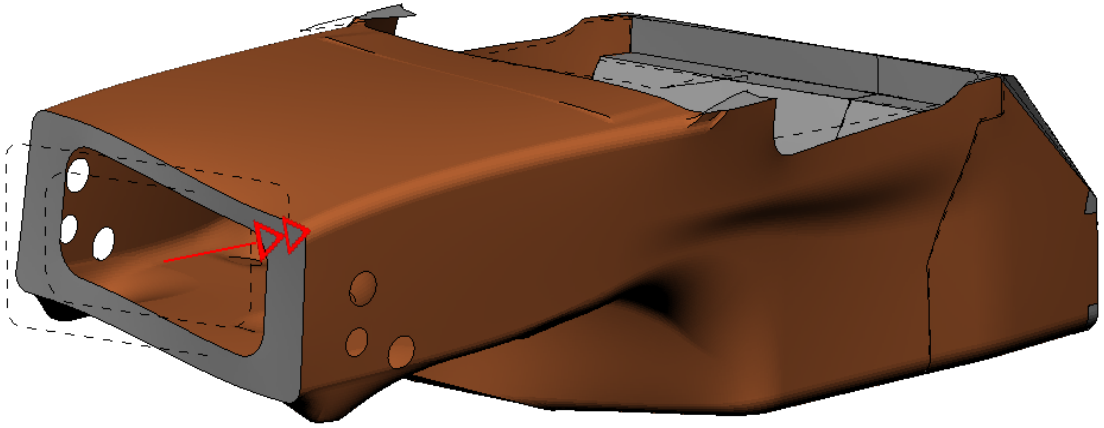
Force x-direction



Force y-direction



Force z-direction



Moment x-direction

STEP1: Optimization setup

- Design space with symmetric laminate and (super-)plies for 0°, 90°, ±45°
- 3 design variables per element
  - 3 'layers' of $DELEMENT TYPE = DTOPO
  - Explicitely balancing ±45° plies
- *Elementwise* (1 constraint per element!) restriction for sum of ply thicknesses
  - $DERESTRAINT TYPE=LAYER
- Assigning elemental design variables to ply properties:
  - $DVTPAR KIND = PLY
- **Optimization Task:** Design constraints on displacements at loaded node for all load cases (limits from reference model) and minimization of weight

```
$DELEMENT TYPE = DTOPO
  1  DSVSET1  :  FREESIZE  ! 0
  2  DSVSET2  :  FREESIZE  ! 90
  3  DSVSET3  :  FREESIZE  ! +/-45
```

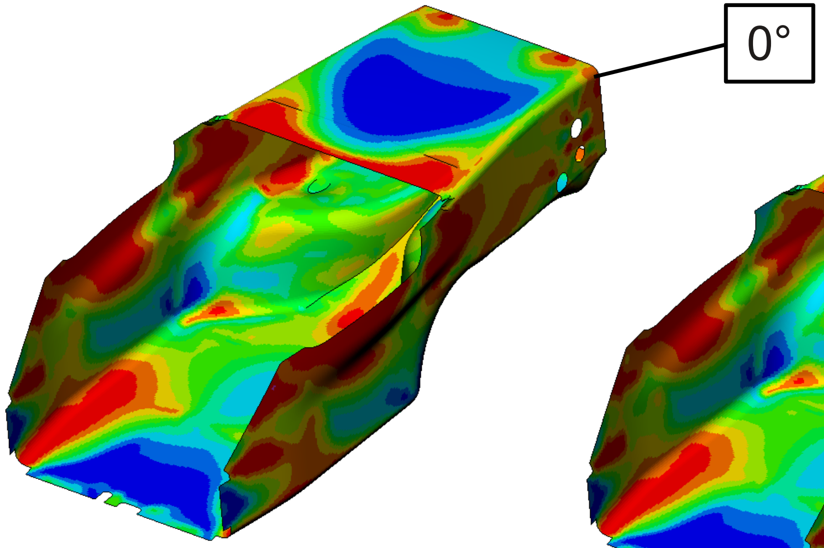
```
$DESET NAME = SP_ALL
   &   SEQUENCE = ORDERED
  1  2  3
$DERESTRAINT TYPE = LAYER
  SP_ALL  101  UPPER = 1.0
$FUNCTION LIB FID = 101  TYPE = 12
  0.0   1.0   1.0   2.0
```

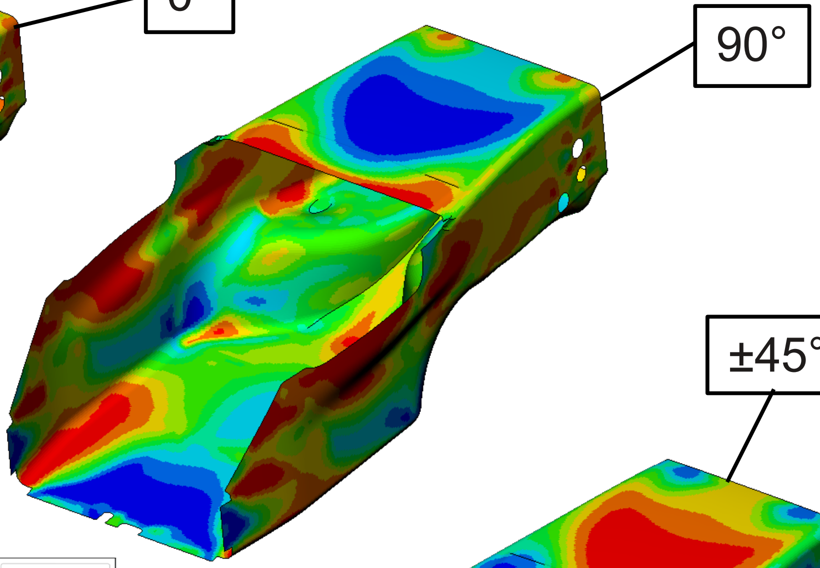
```
$DVTPAR  DEID = 1  KIND = PLY
MAT_7    1    1   !   0
$DVTPAR  DEID = 2  KIND = PLY
MAT_7    3    1   !  90
$DVTPAR  DEID = 3  KIND = PLY
MAT_7    2    1   ! +45
MAT_7    4    1   ! -45
```

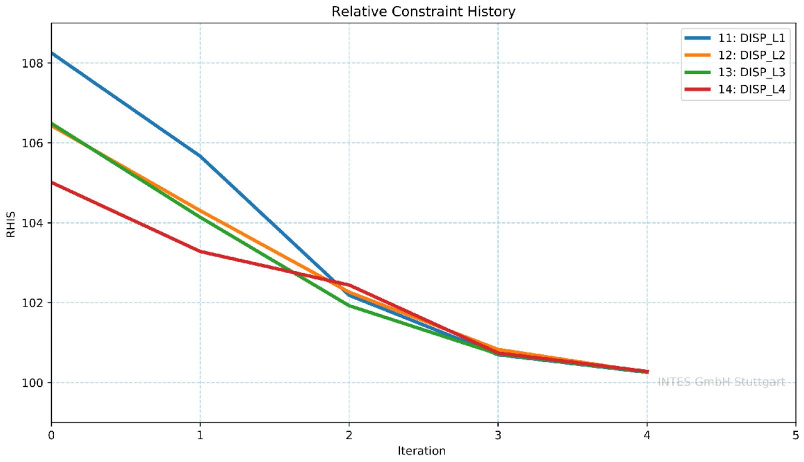
STEP1: Results

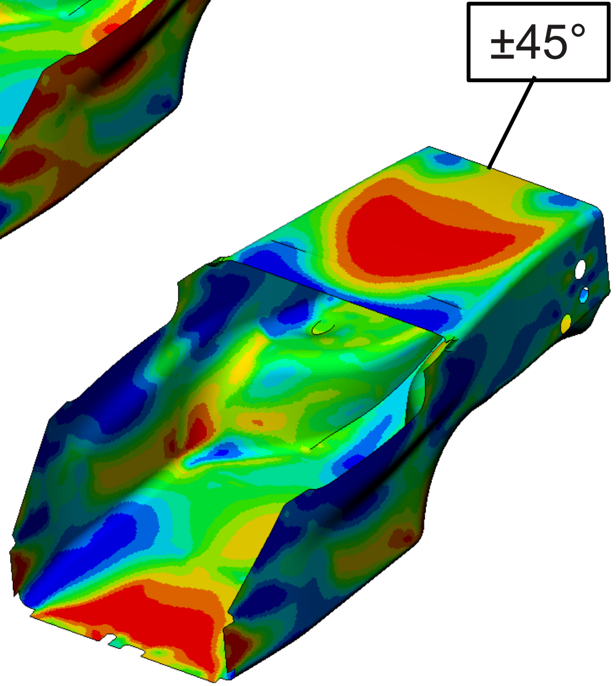
- Convergence after 4 iterations
- Equal thickness distribution for 0° and 90°
- ±45° and 0°/90° thicknesses alternate
  - Important role of max. total thickness restraint
- All displacement constraints fulfilled
- Weight minimization:

Total weight	-4.2%
Design area	-5.9%
Plies in design area	-8.9%







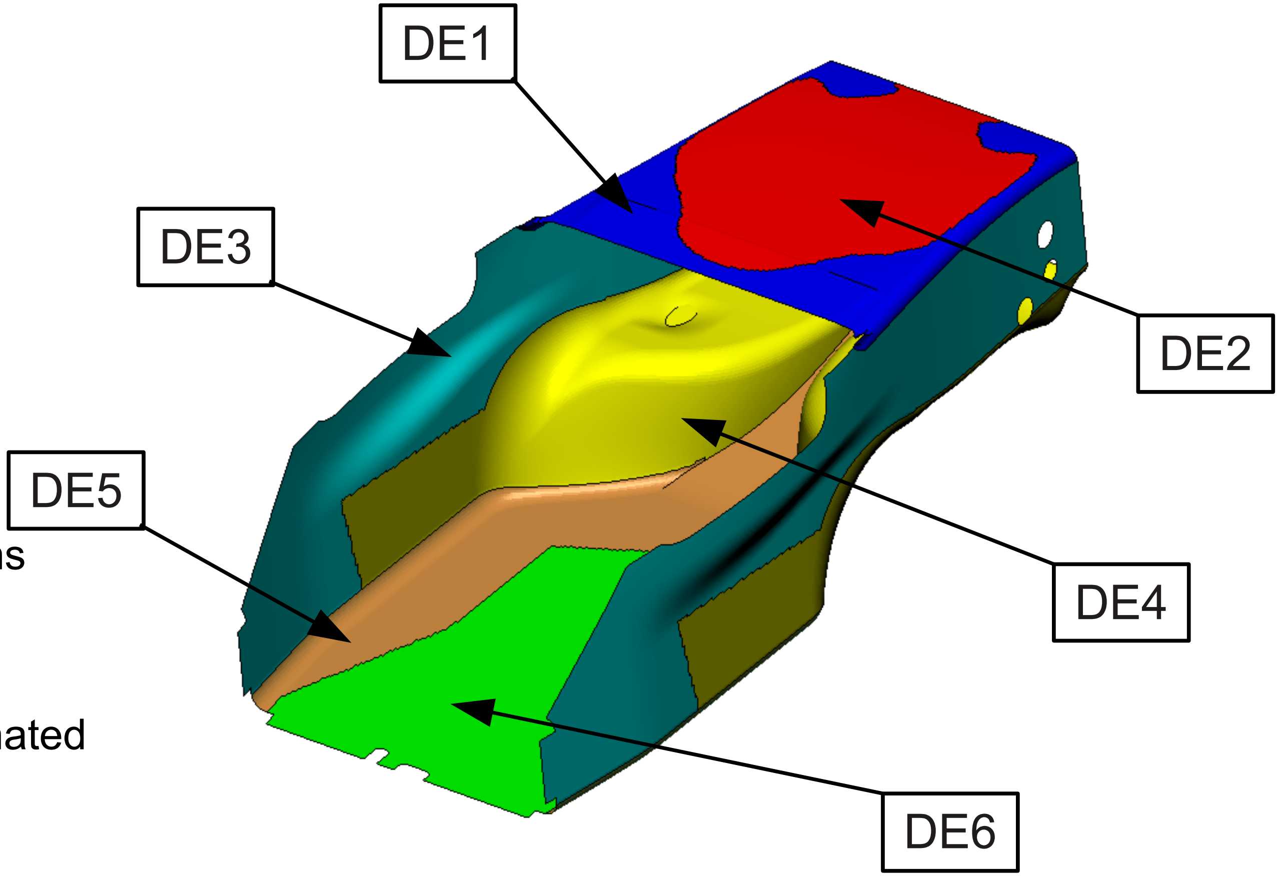


STEP1: Post-processing

- Goal: Divide design area in different regions with similar properties to define new laminates
- Use of elemental thickness result values in any post-processing tool, e.g. VisPER
- PERMAS UCI-command TOOL8 for simple ruled set generation
- Engineering experience and manufacturing considerations essential!
- Here: Simple distinction between 0°/90°- and ±45°-dominated areas and rough transformation into 2x3 design regions:

DE1, DE3, DE5: 0°/90° dominated areas

DE2, DE4, DE6: ±45° dominated areas



STEP2: Optimization setup

- Symmetric laminate and plies for 0°, 90°, ±45°
  - 1 Designelement with 3 variables for 0°, 90° and ±45° for each design region
  - Explicitely balancing ±45° plies
- Assigning elemental design variables to ply properties by
  - $DVMPAR
- Restriction for sum of ply thicknesses with upper and lower bound for each design region by
  - $DCFUNCTION

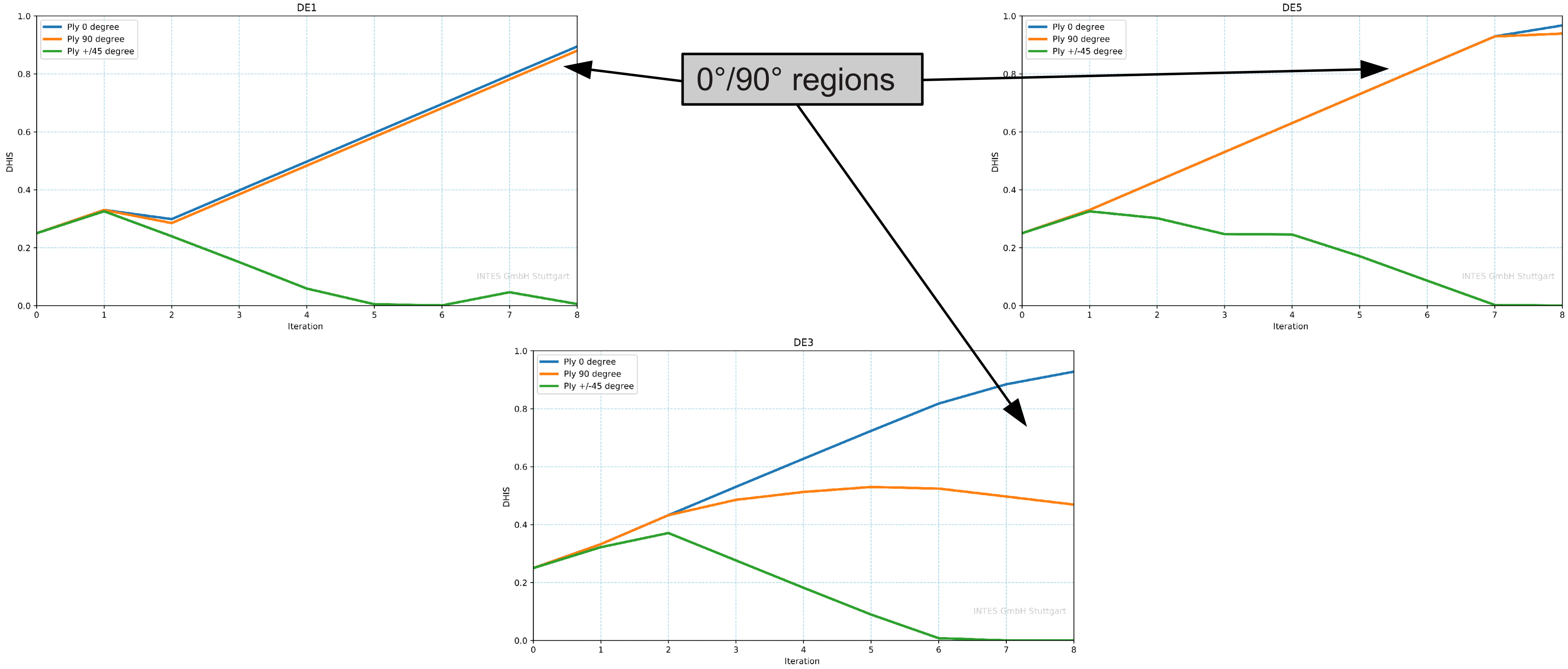
  representing a minimum and maximum nr. of plies
- **Optimization Task:** Displacement constraints and minimization of weight as in STEP1

```
$DELEMENT TYPE = DQUAD4
1   11   12   13      :   DE1
2   21   22   23      :   DE2
3   31   32   33      :   DE3
4   41   42   43      :   DE4
5   51   52   53      :   DE5
6   61   62   63      :   DE6
```

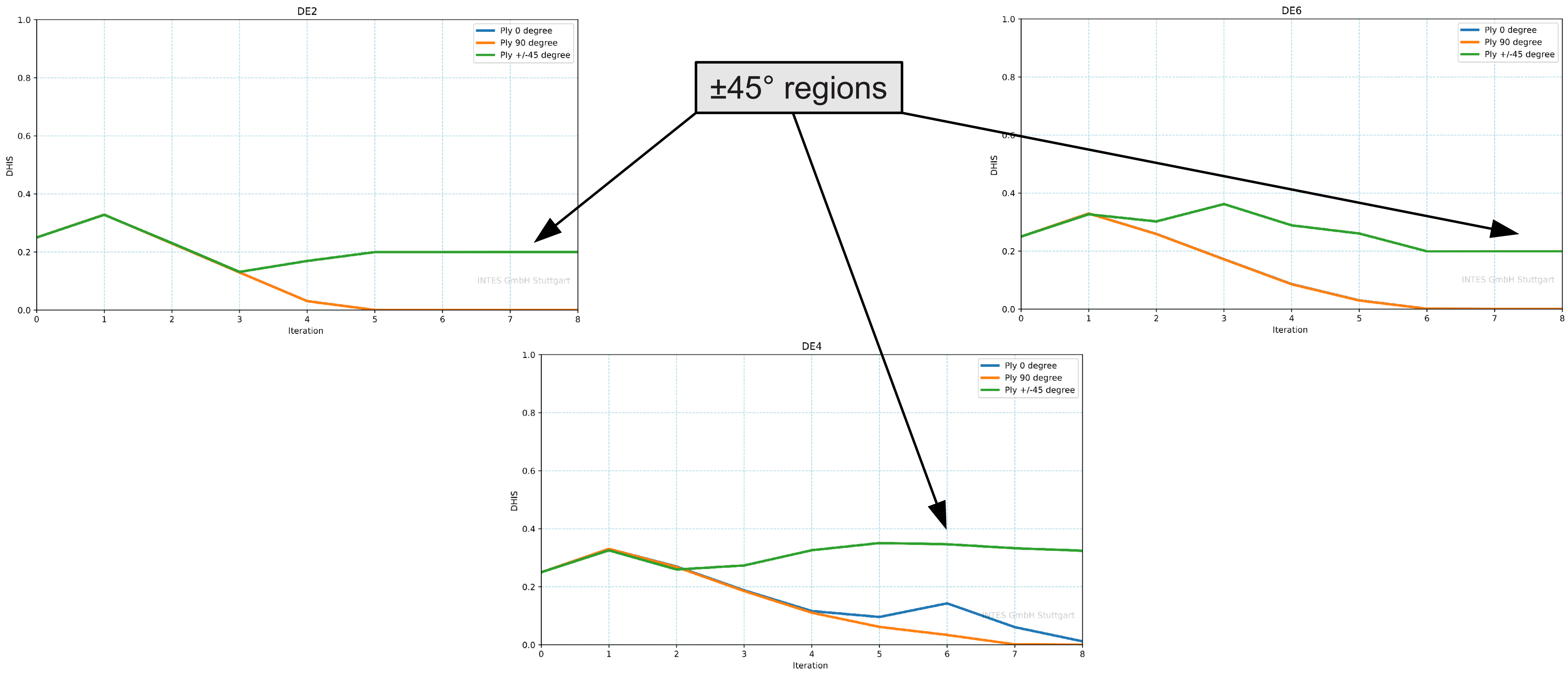
```
$DVMPAR NAME = MAT_DE1  MODE = SCALE
PLY  MAT_7   1    1   :  1.0   :  11
PLY  MAT_7   3    1   :  1.0   :  12
PLY  MAT_7   2    1   :  1.0   :  13
PLY  MAT_7   4    1   :  1.0   :  13
```

```
$DCFUNCTION CSTID = T_DE1 FUNCTION = 101
    & LOWER = ... UPPER = ...
1 DESVAR : 11
2 DESVAR : 12
3 DESVAR : 13
$DCFUNCTION CSTID = T_DE2 FUNCTION = 101
   & LOWER = ... UPPER = ...
...
```

STEP2: Results

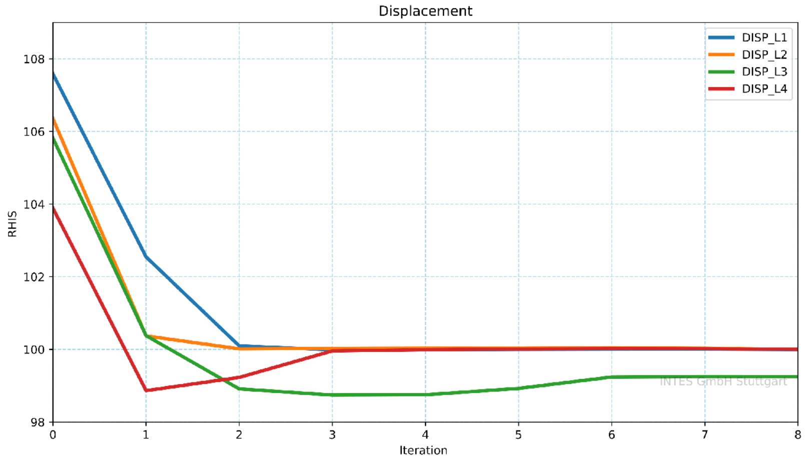


STEP2: Results



STEP2: Results

- Convergence achieved after 8 iterations

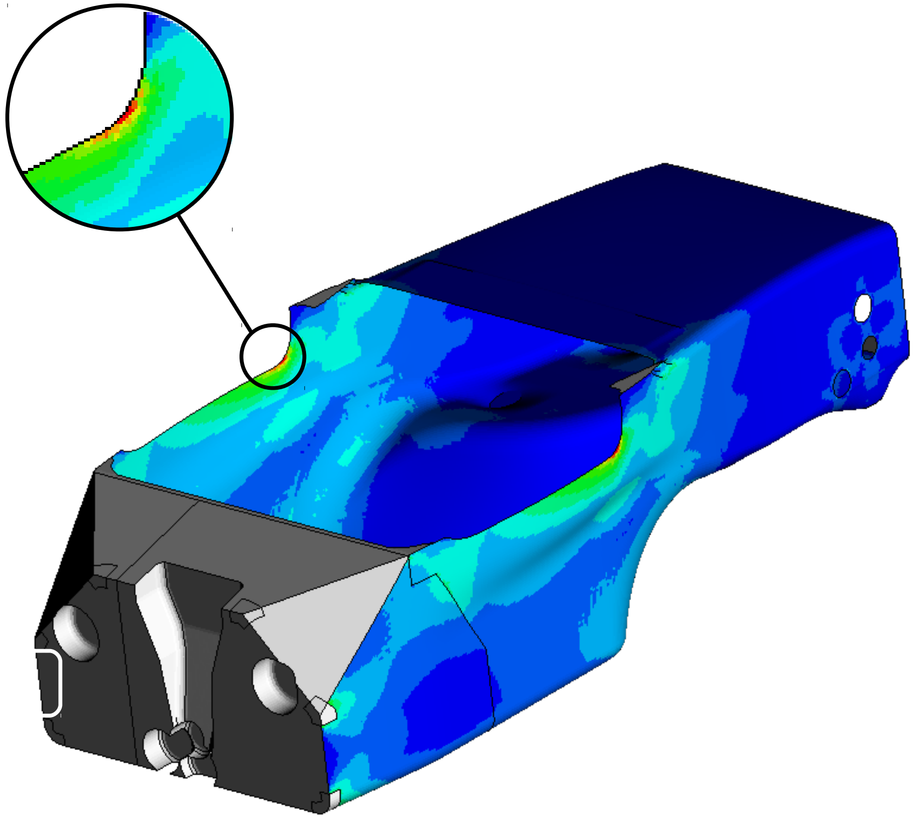


- Weight minimization:

	STEP1	STEP2
Total weight	-4.2%	-2.3%
Design area	-5.9%	-3.2%
Plies in design area	-8.9%	-4.8%

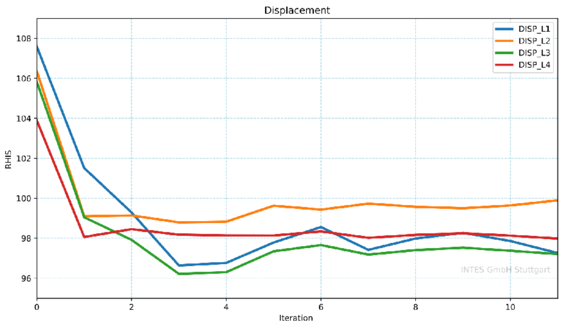
→ Still slightly reducing, but of course less than STEP1

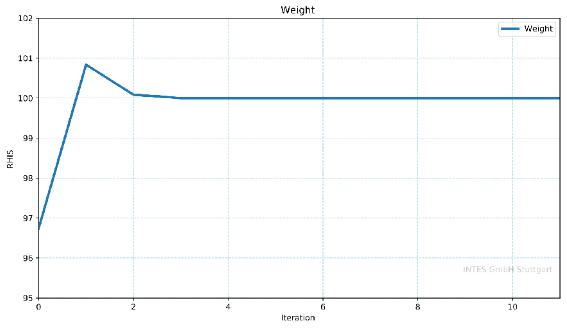
- Plyfailure criterion HOFFMANN of reference model (Failure exposure loadcase 3)



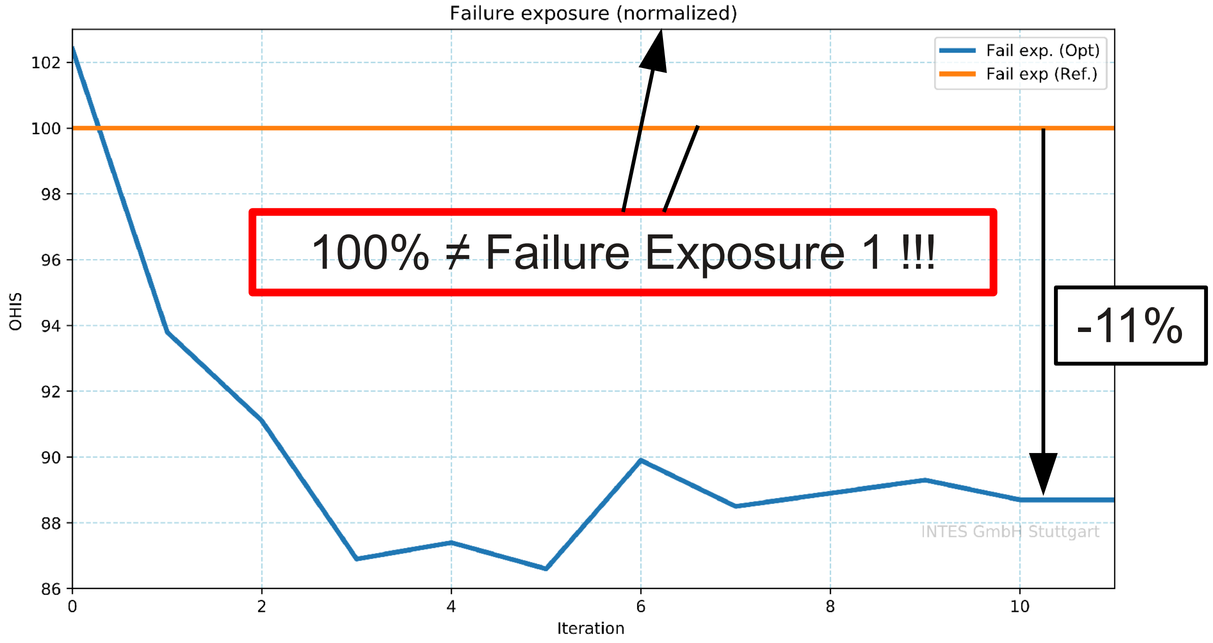
STEP2: Ply failure minimization

- Displacement and weight constraints with limits from reference model
- Minimization of max. failure exposure for loadcase 3
  - reduced failure exposure by ~11%
  - significiant differences in ply thicknesses



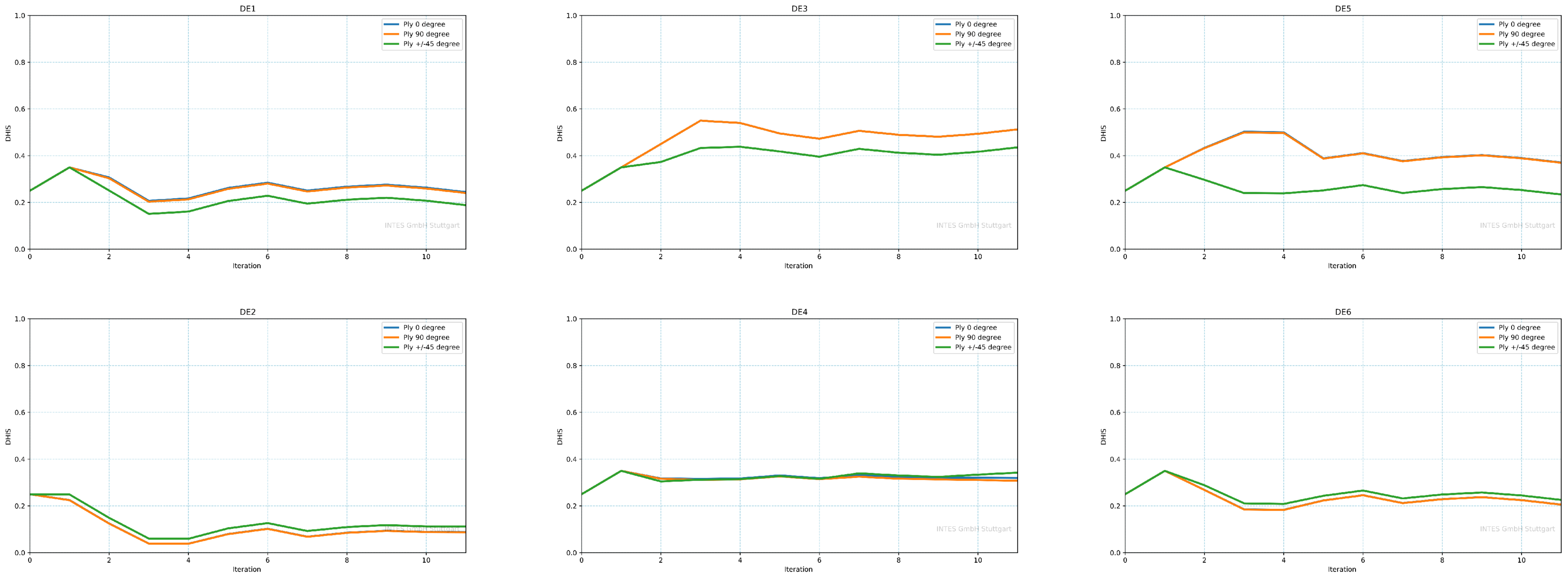



```
$DCONSTRAINT PLYFAILURE TYPE = DMODEL
&      SITUATION = SITUATION_1  LPAT = 3
 PF_L3_1     :   1   no    1.0
 PF_L3_2     :   2   no    1.0
 PF_L3_3     :   3   no    1.0
 PF_L3_4     :   4   no    1.0
 PF_L3_6     :   6   no    1.0
 PF_L3_7     :   7   no    1.0
 PF_L3_8     :   8   no    1.0
 PF_L3_9     :   9   no    1.0
$DOBJECT CONSTRAINT = PF_L3_1 PF_L3_2 PF_L3_3
  & PF_L3_4 PF_L3_6 PF_L3_7 PF_L3_8 PF_L3_9
```



Ply failure minimization: Results

Distinction between 0°/90° and ±45° regions much smaller!



Summary

- A basic procedure to design laminates has been presented for the example of a racing car monocoque. This procedure consists of two steps:
  - STEP1: 'Freesize' for the generation of ply shapes, hence appropriate design regions for the second step
  - STEP2: Classical 'Sizing' for optimizing the ply stacks of pre-defined laminates
- In both steps, various additional restrictions such as balancing different fiber orientations or restricting total thicknesses can be incorporated
- Even though a very simple approach to transfer results from STEP1 at least similar results (w.r.t weight and stiffness) compared to an existing reference monocoque could be achieved
- Failure exposure could be minimized in alternative optimization setup (while weight and stiffness stay the same)
  - Major impact on optimized design

Outlook

- Evaluation of new laminate optimization capabilities is a still ongoing process. This includes to
  - exploit fiber angles as additional degrees of freedom for optimization
  - generate more sophisticated and detailed realization of ply shapes from STEP1 results
  - examine the effect of approximating STEP2 results with discrete number of plies
- Likewise development of optimization methods and related software tools is not yet terminated. Future work could consider
  - the incorporation of additional analysis responses, e.g. buckling loads
  - improved methods for the automatic generation of appropriate ply shapes and their reuse
  - the design and implementation of GUI support for optimization setup and evaluation
  - the ability of optimization algorithms to treat discrete variables

Thank you for your attention!