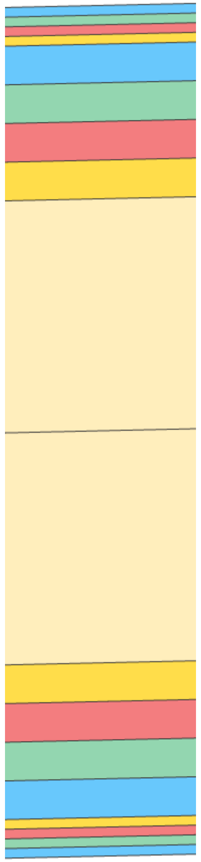
Workshop – Ply Number Optimization of a Composite Laminate

AN MSC NASTRAN SOL 200 TUTORIAL

Goal: Use Nastran SOL 200 Optimization



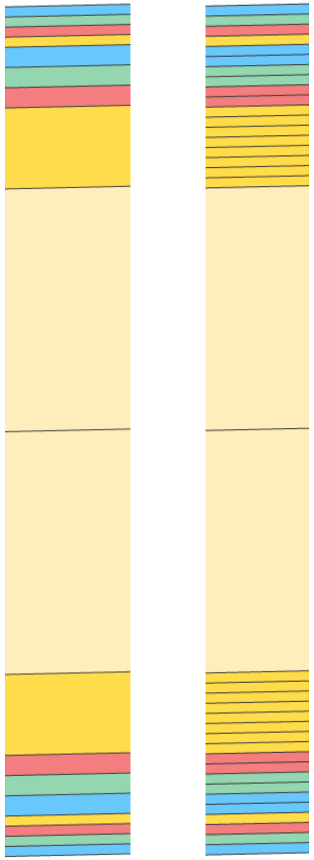
Objective: Minimize the weight of this cylinder composed of a composite laminate

Before Optimization

- Weight: 3.997805 $lb_f \cdot s^2/in$
- Layup: $[45/-45/90/0/45/45/45/45/-45/-45/-45/-45/90/90/90/90/0/0/0/0/0_{core}]_S$
- Total Thickness: .44 in
- Max failure index (Tsai-Hill): 1.687933

After Optimization

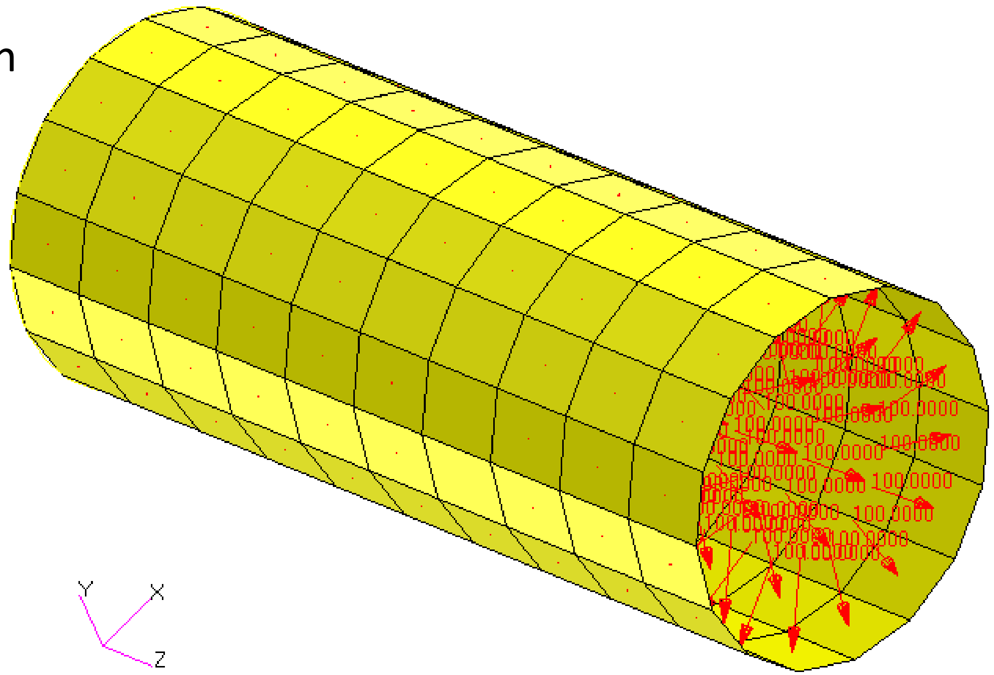
- Weight: 3.598260 $lb_f \cdot s^2/in$
- Layup: $[45/-45/90/0/45/45/-45/-45/90/90/0/0/0/0/0/0/0/0/0_{core}]_S$
- Total Thickness: .42 in
- Max failure index (Tsai-Hill): .8579478



Details of the Structural Model

Allowed to translate in x and y

Translation prevented in z direction



Internal pressure load of 1400 psi

Optimization Problem Statement

Design Variables

Layer Thickness Variables
+/- 45 degree layers
PCOMP 1
x1: Thickness of layer 5
x2: Thickness of layer 6
x3: Thickness of layer 13
x4: Thickness of layer 14
PCOMP 2
x5: Thickness of layer 5
x6: Thickness of layer 6
x7: Thickness of layer 13
x8: Thickness of layer 14
90 degree layers
PCOMP 1
x9: Thickness of layer 7
x10: Thickness of layer 12
PCOMP 2
x11: Thickness of layer 7
x12: Thickness of layer 12
0 degree layers
PCOMP 1
x13: Thickness of layer 8
x14: Thickness of layer 11
PCOMP 2
x15: Thickness of layer 8
x16: Thickness of layer 11

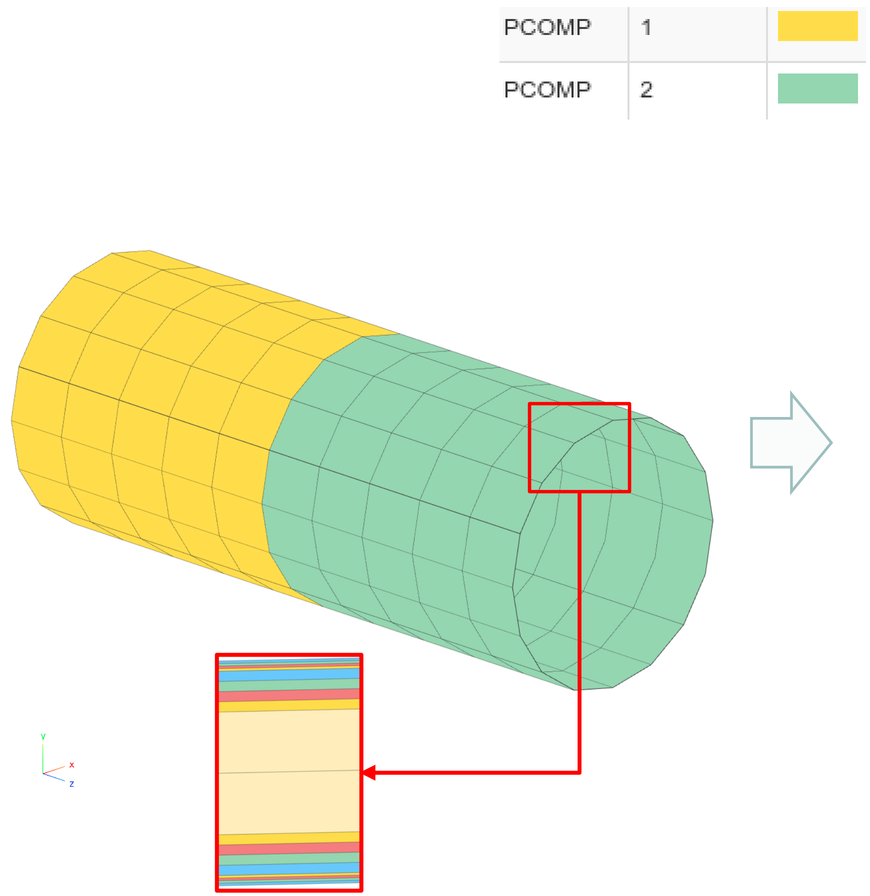
Ply Number Variables

y1: Number of variables +/- 45 degrees
y2: Number of variables 90 degrees
y3: Number of variables 0 degrees

Allowed Values: 1, 2, 3, ..., 100 (Ply numbers)

Variable Relationships (DLINK)

x1, x2, x3, x4, x5, x6, x7, x8 = y * 0.005
x9, x10, x11, x12 = y2 * 0.005
x13, x14, x15, x16 = y3 * 0.005



Design Objective

r0: Minimize weight

Design Constraints

r1: Failure index (Hill) of layer 1 for PCOMP 1 and 2
r2: Failure index (Hill) of layer 2 for PCOMP 1 and 2
r3: Failure index (Hill) of layer 3 for PCOMP 1 and 2
r4: Failure index (Hill) of layer 4 for PCOMP 1 and 2
r5: Failure index (Hill) of layer 15 for PCOMP 1 and 2
r6: Failure index (Hill) of layer 16 for PCOMP 1 and 2
r7: Failure index (Hill) of layer 17 for PCOMP 1 and 2
r8: Failure index (Hill) of layer 18 for PCOMP 1 and 2

r1, … r8 < .95

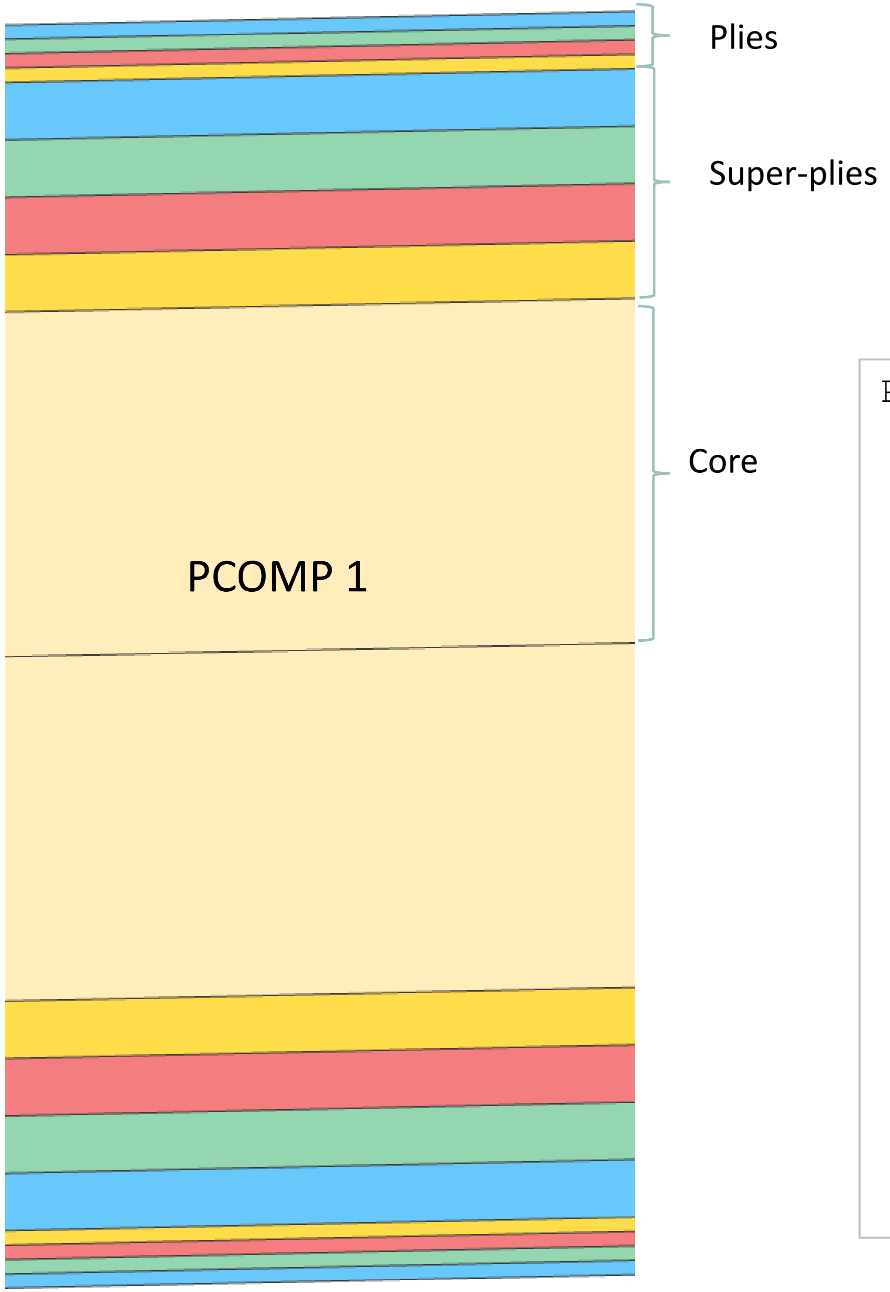
5 Load Cases

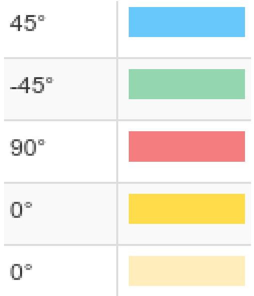
Terminology

- All rows on the PCOMP entry are layers
- Each layer may correspond to one of the following
  - Ply
  - Super-ply
  - Core

For this PCOMP example, 18 layers are defined.

- Layers 1, 2, 3, 4, 15, 16, 17 and 18 have a thickness 0.005 inches and is the thickness of a ply. These layers are plies.
- Layers 5, 6, 7, 8, 11, 12, 13 and 14 have a thickness greater than 0.005 inches and represent multiple plies grouped as one layer. The thickness of one of these layers is 0.02 inches (0.005*4), or equal to the thickness of 4 plies. These layers are super-plies.
- Layers 9 and 10 correspond to the core. These layers are core layers.

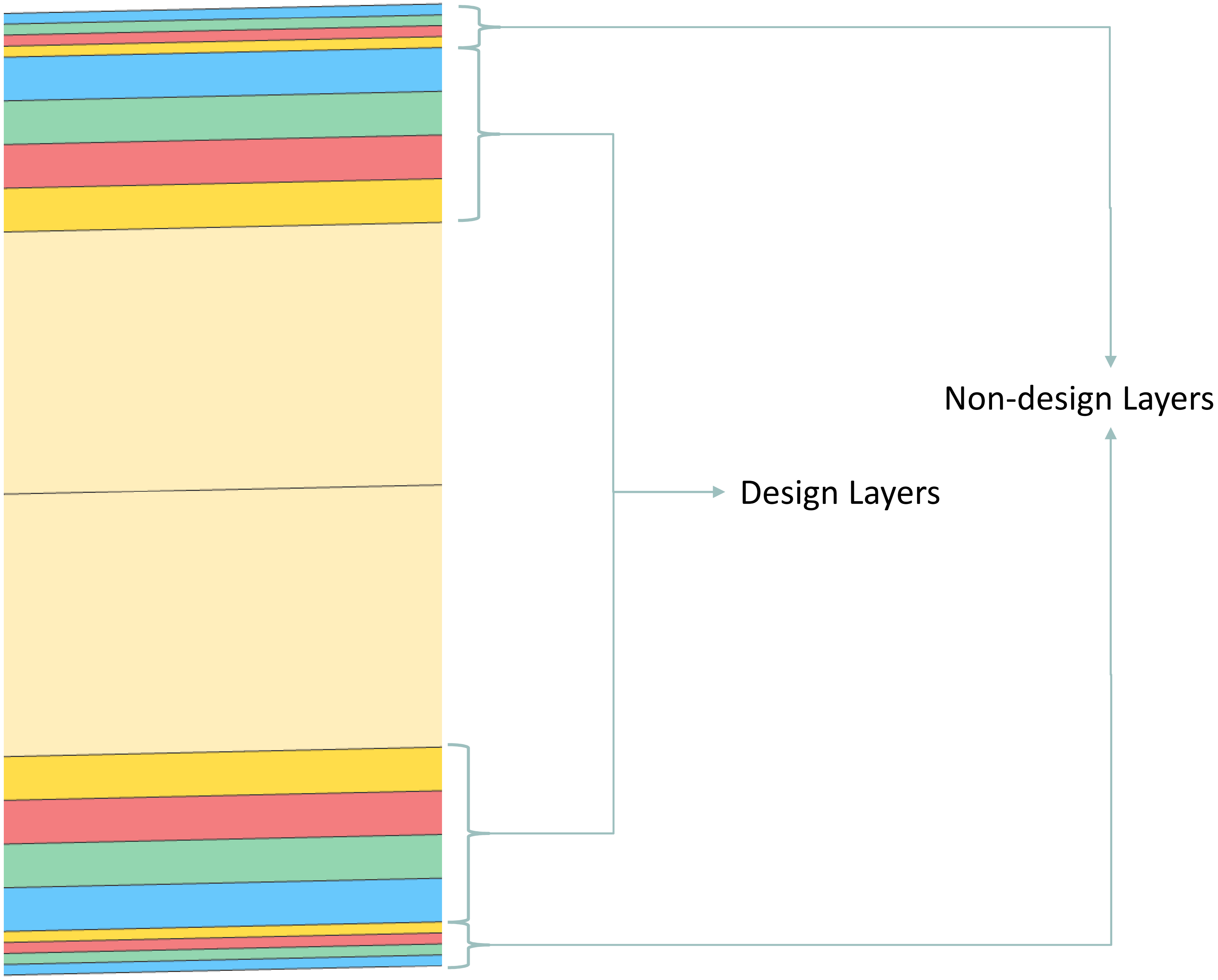




PCOMP	1			13000.
	1	.005	45.	YES
	1	.005	-45.	YES
	1	.005	90.	YES
	1	.005	0.	YES
	1	.02	45.	YES
	1	.02	-45.	YES
	1	.02	90.	YES
	1	.02	0.	YES
	501	.12	0.	NO
	501	.12	0.	NO
	1	.02	0.	YES
	1	.02	90.	YES
	1	.02	-45.	YES
	1	.02	45.	YES
	1	.005	0.	YES
	1	.005	90.	YES
	1	.005	-45.	YES
	1	.005	45.	YES

Design Layers

- Design Layers – The thickness of layers 5, 6, 7, 8, 11, 12, 13 and 14 are allowed to vary during the optimization. The failure index of these layers is not considered during the optimization.
- Non-design Layers – The thickness of the outer layers 1, 2, 3, 4, 15, 16, 17 and 18 is NOT varied during the optimization and remains constant. The failure index of these outer layers is considered and constrained during the optimization.



Design Variables

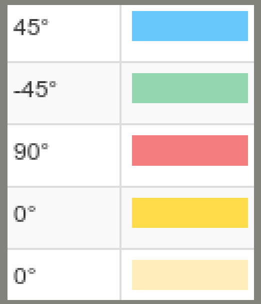
- Most applications will involve optimization of multiple PCOMP entries, so this tutorial demonstrates the process of optimizing multiple PCOMP entries.
- To keep the exercise simple, both PCOMP entries define identical laminates.

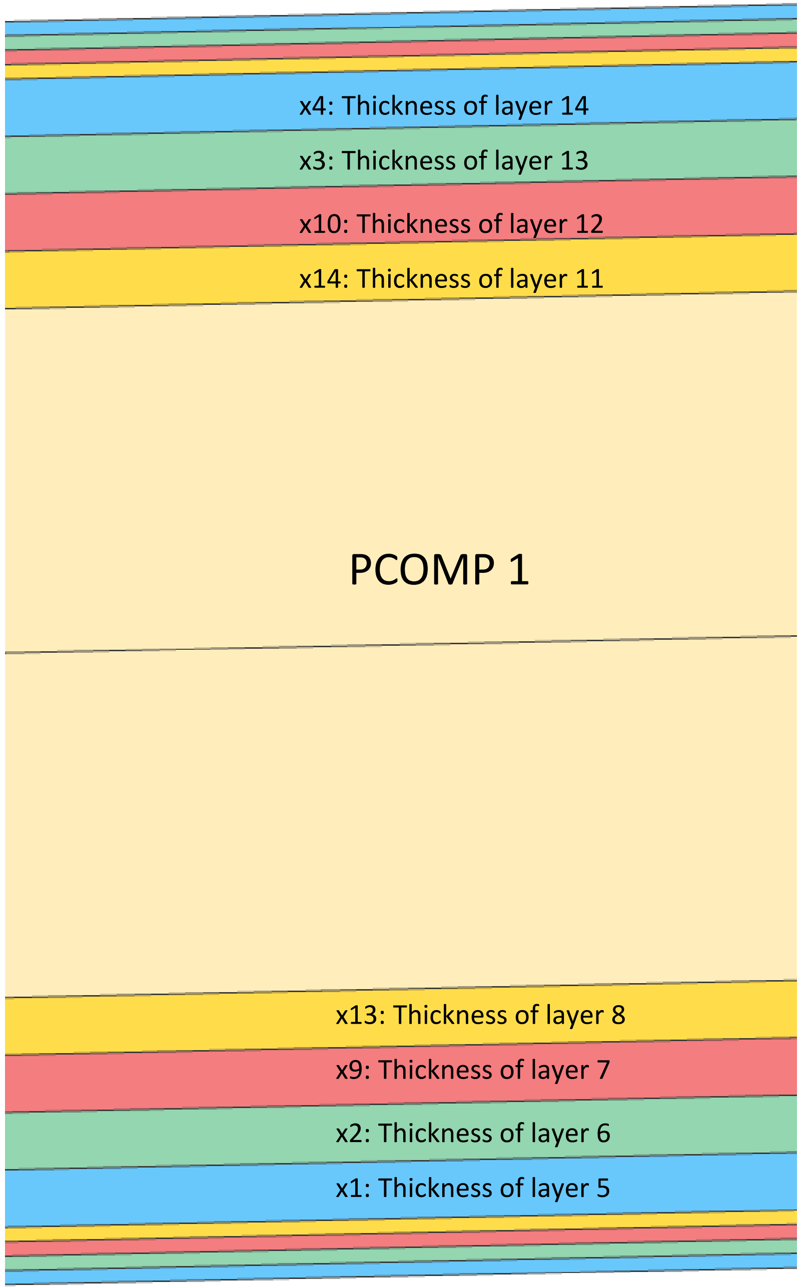
```
PCOMP   1                               13000.
        1       .005    45.     YES
        1       .005    -45.    YES
        1       .005    90.     YES
        1       .005    0.      YES
        1       .02     45.     YES
        1       .02     -45.    YES
        1       .02     90.     YES
        1       .02     0.      YES
        501     .12     0.      NO
        501     .12     0.      NO
        1       .02     0.      YES
        1       .02     90.     YES
        1       .02     -45.    YES
        1       .02     45.     YES
        1       .005    0.      YES
        1       .005    90.     YES
        1       .005    -45.    YES
        1       .005    45.     YES
```

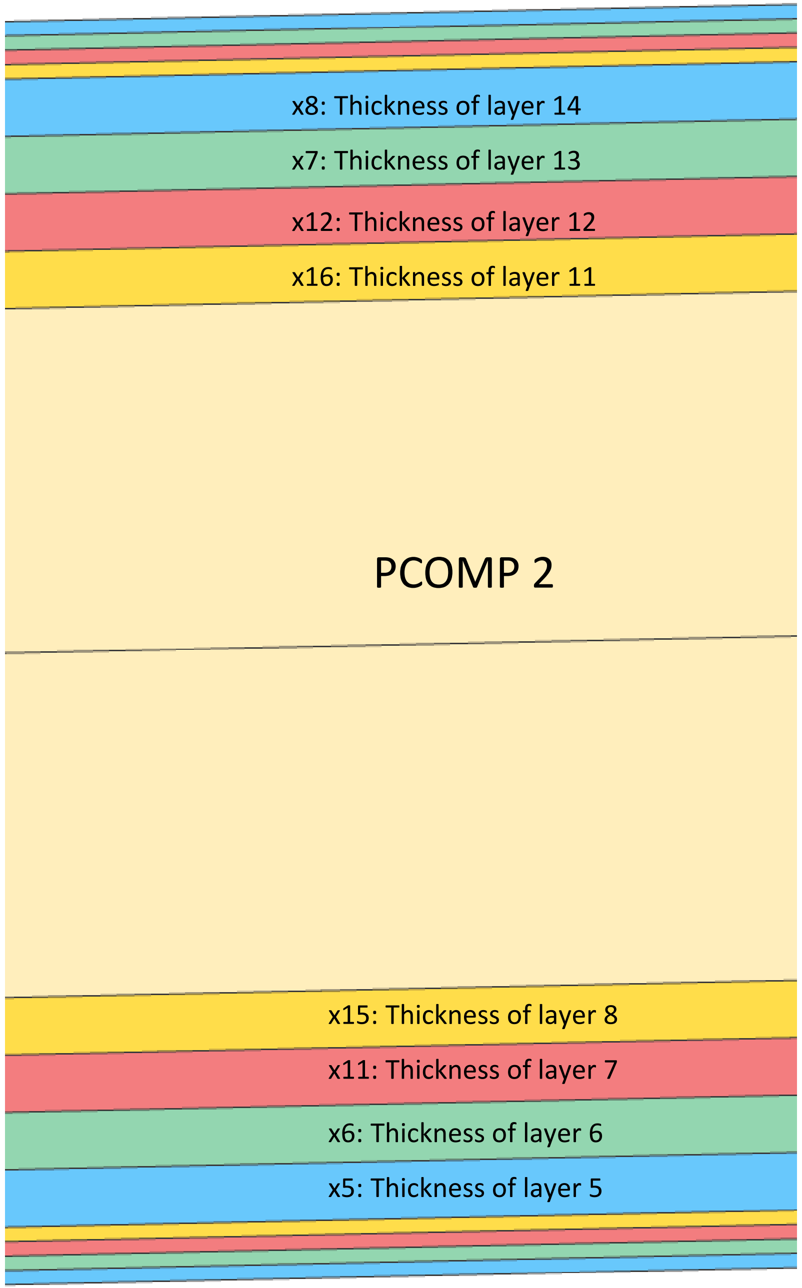
```
PCOMP   2                               13000.
        1       .005    45.     YES
        1       .005    -45.    YES
        1       .005    90.     YES
        1       .005    0.      YES
        1       .02     45.     YES
        1       .02     -45.    YES
        1       .02     90.     YES
        1       .02     0.      YES
        501     .12     0.      NO
        501     .12     0.      NO
        1       .02     0.      YES
        1       .02     90.     YES
        1       .02     -45.    YES
        1       .02     45.     YES
        1       .005    0.      YES
        1       .005    90.     YES
        1       .005    -45.    YES
        1       .005    45.     YES
```

Design Variables

- 16 design variables are created to vary the thickness of the indicated layers
- The thickness of the inner most layers are optimized.
- The thicknesses of the outer most layers (plies) are NOT varied during the optimization and remains constant.
- The thickness of the core layers are NOT varied.

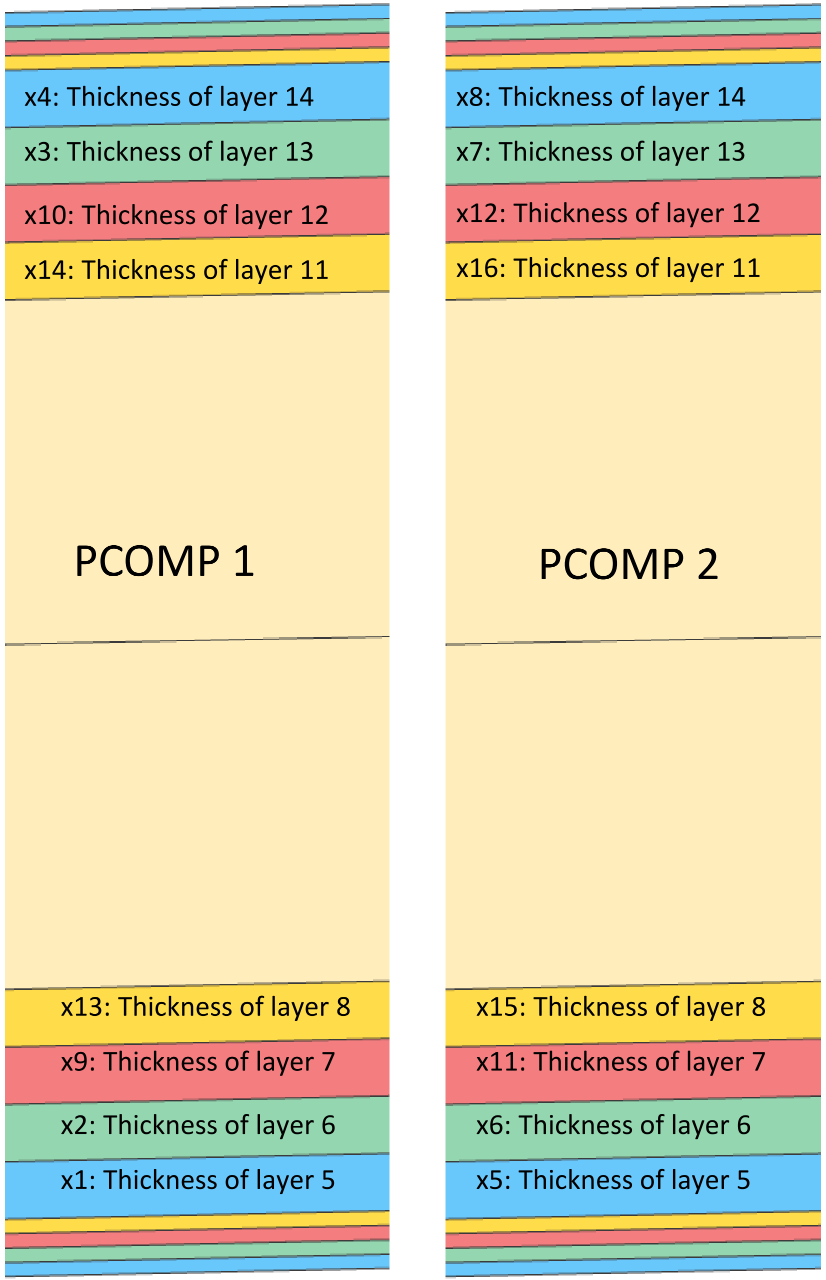






Design Variables

- Since the goal is to determine the number of optimal plies, ply number variables are created.
- The ply number variables are associated to the thickness variables via the displayed relationships.
- The ply number variables are allowed to be discrete values of 1, 2, 3, …, etc.



Ply Number Variables

y1: Number of variables +/- 45 degrees
y2: Number of variables 90 degrees
y3: Number of variables 0 degrees

Variable Relationships

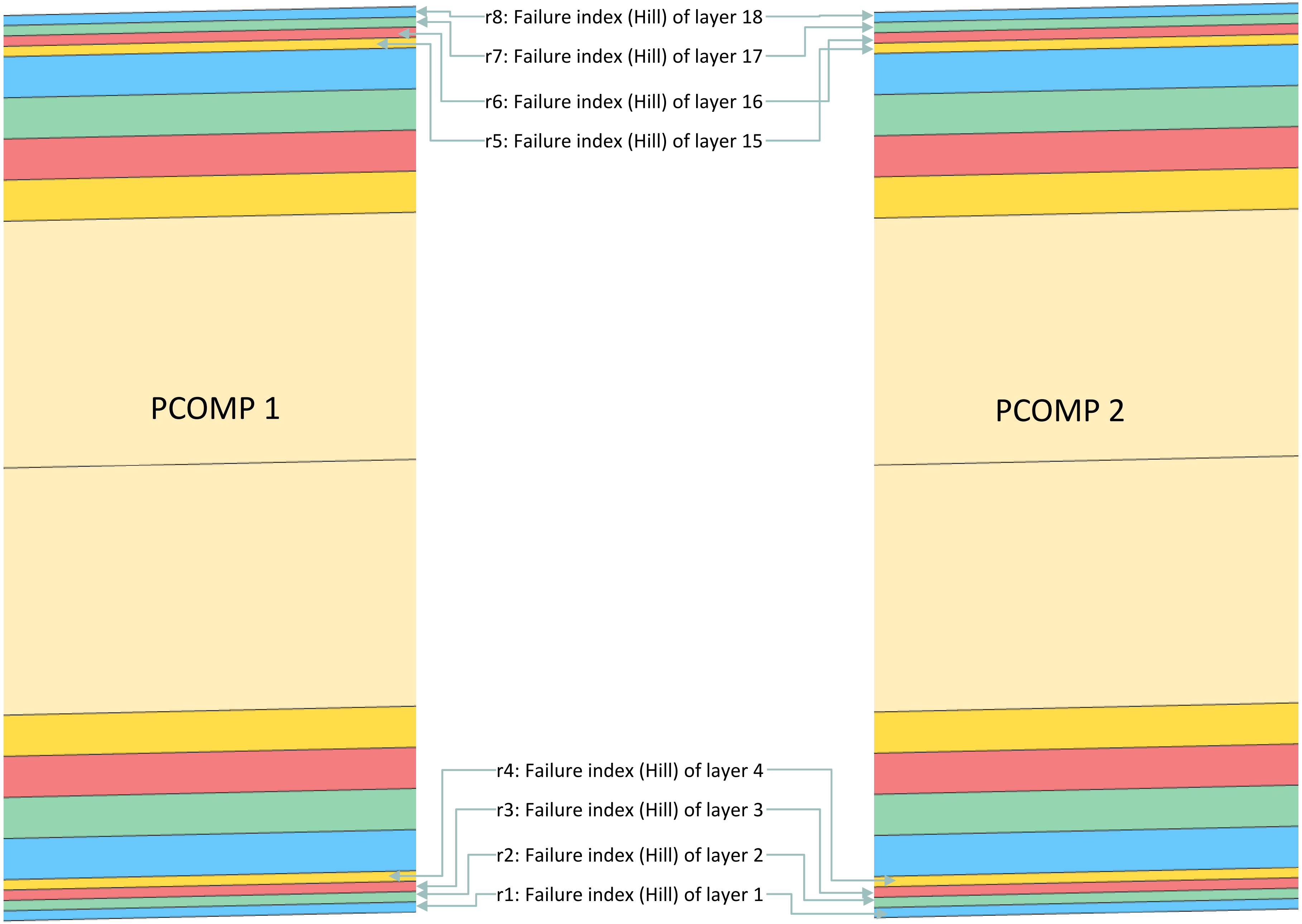
$x1 = y1 * 0.005$
$x2 = y1 * 0.005$
$x3 = y1 * 0.005$
$x4 = y1 * 0.005$
$x5 = y1 * 0.005$
$x6 = y1 * 0.005$
$x7 = y1 * 0.005$
$x8 = y1 * 0.005$

$x9 = y2 * 0.005$
$x10 = y2 * 0.005$
$x11 = y2 * 0.005$
$x12 = y2 * 0.005$

$x13 = y3 * 0.005$
$x14 = y3 * 0.005$
$x15 = y3 * 0.005$
$x16 = y3 * 0.005$

Design Constraints

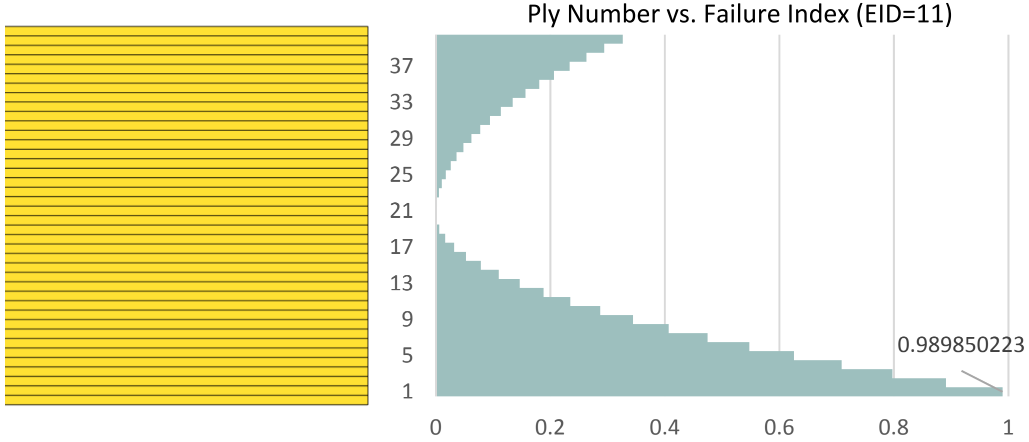
- The failure indices for the outer most layers are constrained.
- Most tutorials consider only 1 load case. This tutorial considers 5 load cases.



Consideration of PCOMP

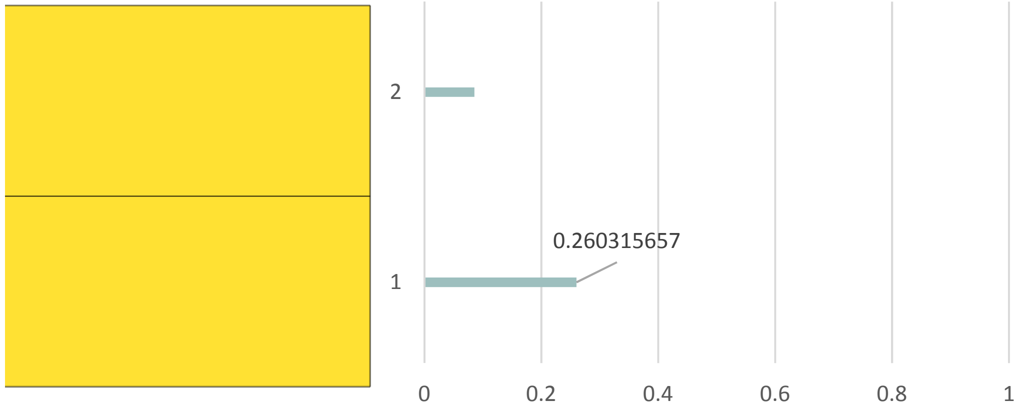
- Layer responses are output for the midplane.
- Consider PCOMP configuration A, B and C.
  - PCOMP A – 40 plies (Total thickness 5 mm)
  - PCOMP B – 2 super-plies (Total thickness 5mm)
  - PCOMP C – 2 plies and 2 super-plies (Total thickness 5mm)
- Each of these PCOMPs produces the same stiffness.
- PCOMP A and C yield the same maximum failure index of 0.98985, but PCOMP B yields a maximum failure index of 0.26032. PCOMP A and C have one thing in common, the outer most layers have a thickness of a ply, where as PCOMP B does not.
- In this tutorial, the outer most layers have a thickness equal to a ply thickness. The failure indices are constrained for the outer most ply layers. The failure indices for the super-ply layers are NOT constrained since these failure indices are misleading.

A



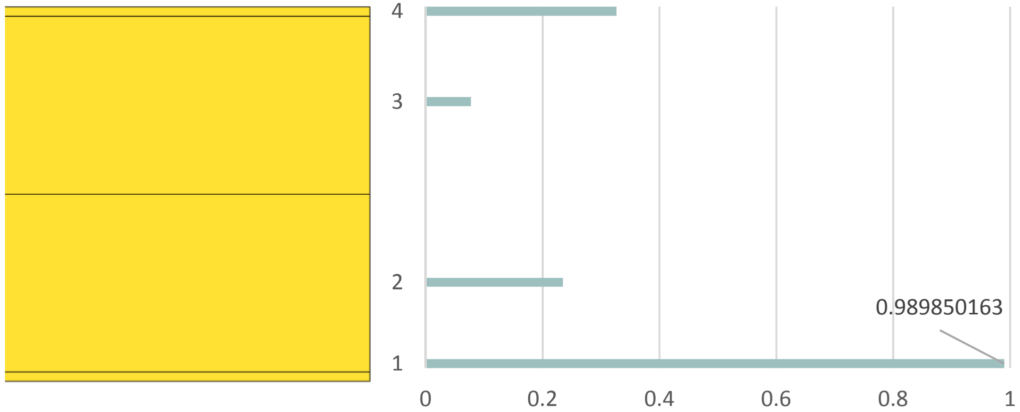

```
PCOMP, 1,,,90., HILL,,
          101      .125    0.        YES
          101      .125    0.        YES
[…] A total of 36 layers are repeated
          101      .125    0.        YES
          101      .125    0.        YES
```

B




```
PCOMP, 1,,,90., HILL,,
          101     2.5      0.        YES
          101     2.5      0.        YES
```

C



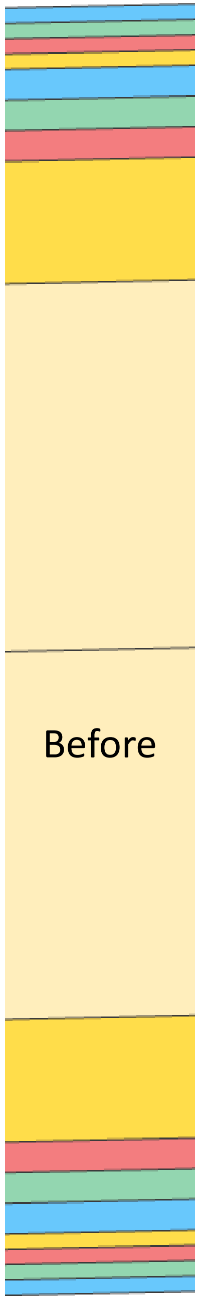

```
PCOMP, 1,,,90., HILL,,
          101      .125    0.        YES
          101     2.375    0.        YES
          101     2.375    0.        YES
          101      .125    0.        YES
```

Updating the PCOMP Entry

- The updated PCOMP entries in the file model.pch contain layers that must be split into corresponding plies

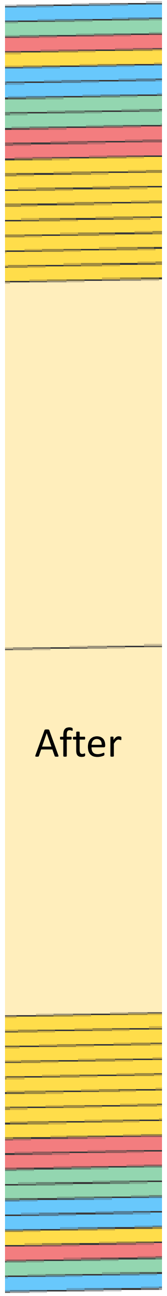
File: model.pch

```
PCOMP          1            0.0    13000.
               1 .005     45.             YES
               1 .005    -45.             YES
               1 .005     90.             YES
               1 .005       0.0           YES
               1 .01      45.             YES
               1 .01     -45.             YES
               1 .01      90.             YES
               1 .04        0.0           YES
             501 .12        0.0            NO
             501 .12        0.0            NO
               1 .04        0.0           YES
               1 .01      90.             YES
               1 .01     -45.             YES
               1 .01      45.             YES
               1 .005       0.0           YES
               1 .005     90.             YES
               1 .005    -45.             YES
               1 .005     45.             YES
```



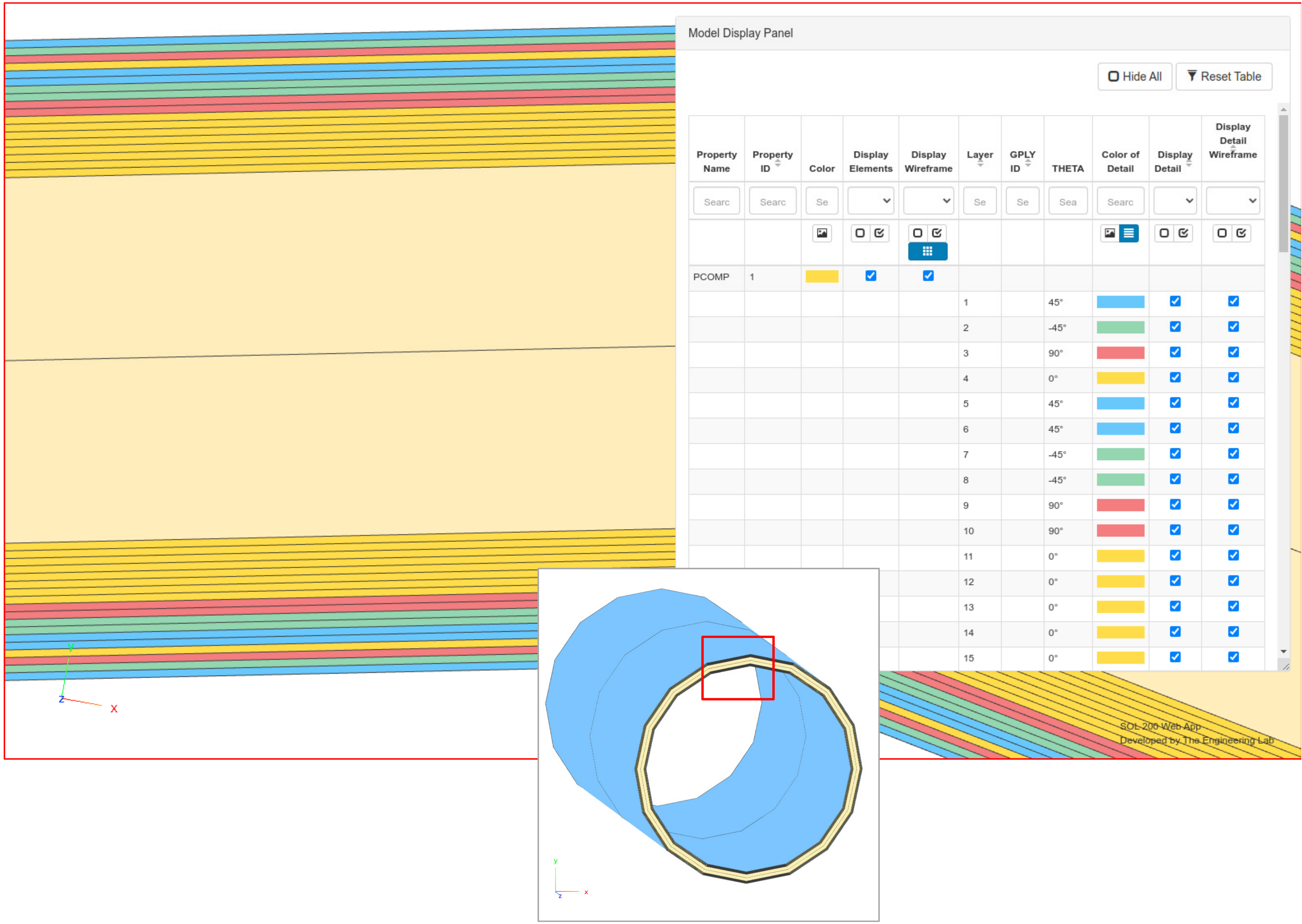
design_pcomps_updated.pch

```
PCOMP   1               0.0     13000.
        1       .005    45.     YES
        1       .005    -45.    YES
        1       .005    90.     YES
        1       .005    0.0     YES
        1       0.005   45.     YES
        1       0.005   45.     YES
        1       0.005   -45.    YES
        1       0.005   -45.    YES
        1       0.005   90.     YES
        1       0.005   90.     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        501     .12     0.0     NO
        501     .12     0.0     NO
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   0.0     YES
        1       0.005   90.     YES
        1       0.005   90.     YES
        1       0.005   -45.    YES
        1       0.005   -45.    YES
        1       0.005   45.     YES
        1       0.005   45.     YES
        1       .005    0.0     YES
        1       .005    90.     YES
        1       .005    -45.    YES
        1       .005    45.     YES
```



Final Laminate

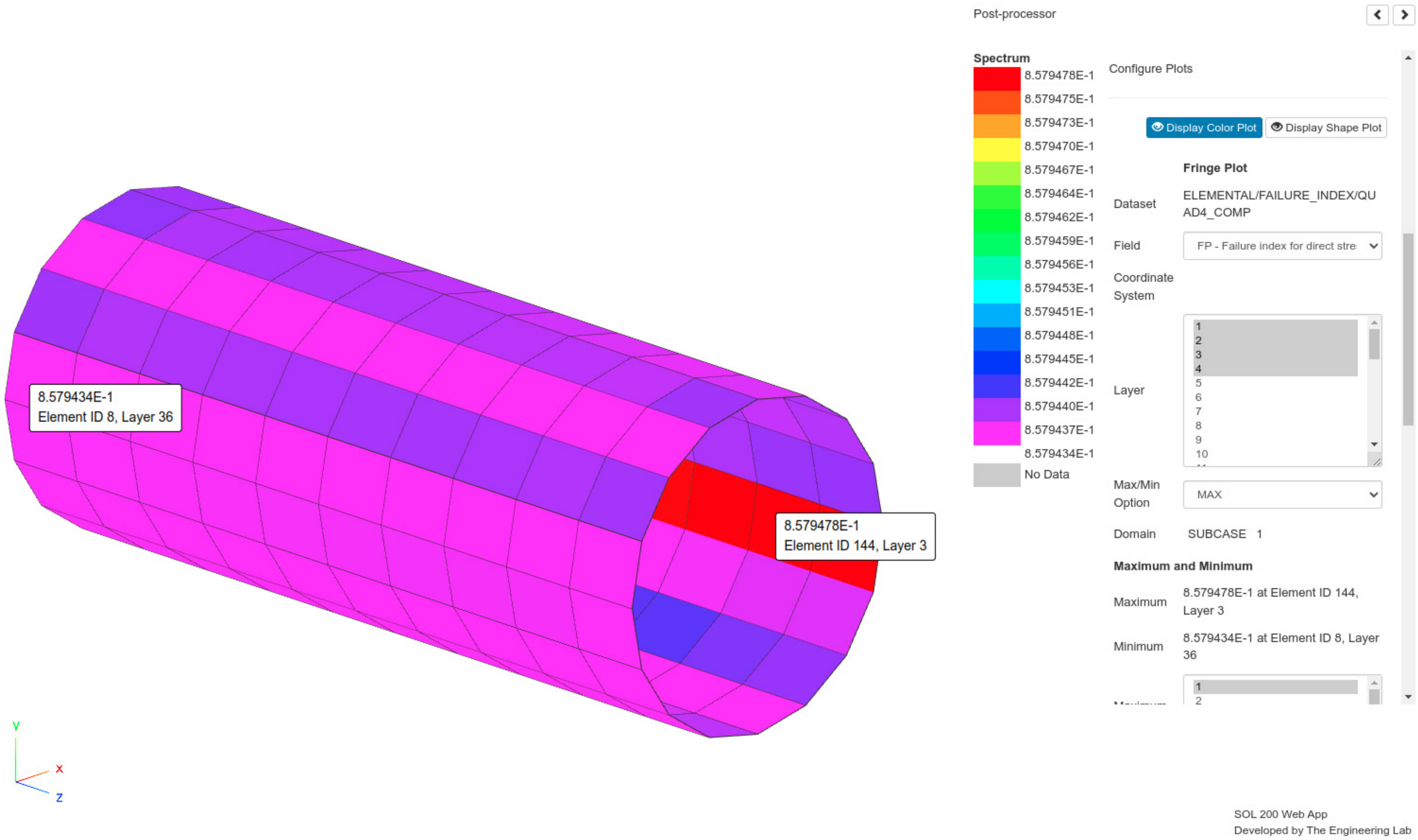
- The Viewer web app is used to visualize the final laminate and plies.



HEXAGON Technology Partner

Final Failure Indices

- The Viewer is also used to inspect the final failure indices.
- The maximum failure index is less than 1.0. The final deign is feasible.



Future Work – Stacking Sequence Optimization

- Stacking sequence optimization
    - Refer to other tutorials

Contact me

- Nastran SOL 200 training
- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

christian@ the-engineering-lab.com

SOL 200 Web App Capabilities

The Post-processor Web App and HDF5 Explorer are free to MSC Nastran users.

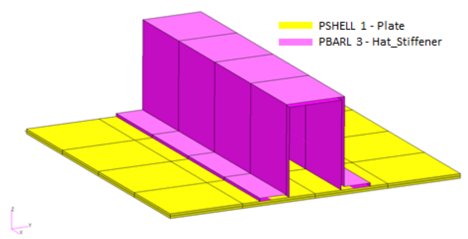
Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge
- Windows and Red Hat Linux
- Installable on a company laptop, workstation or server. All data remains within your company.

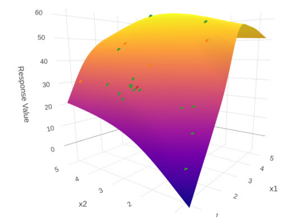
Benefits

- REAL TIME error detection. 200+ error validations.
- REALT TIME creation of bulk data entries.
- Web browser accessible
- Free Post-processor web apps
- +80 tutorials

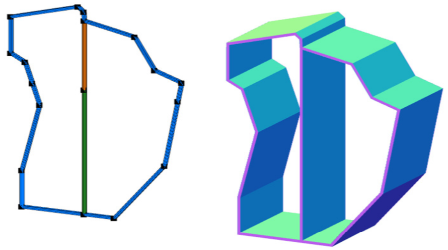
Web Apps



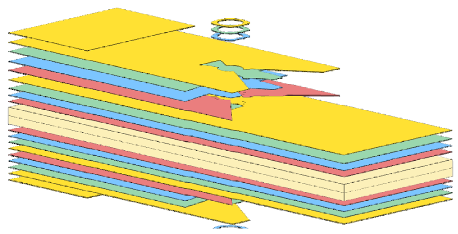
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



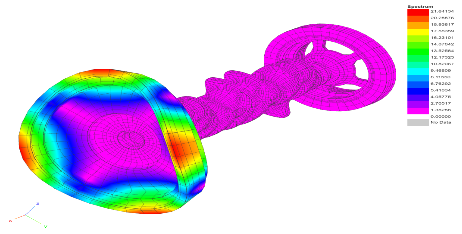
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



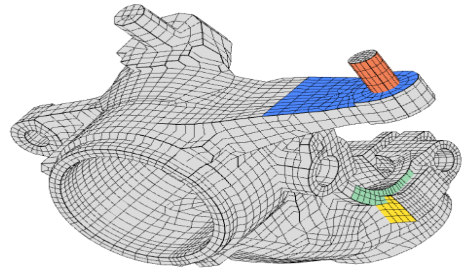
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



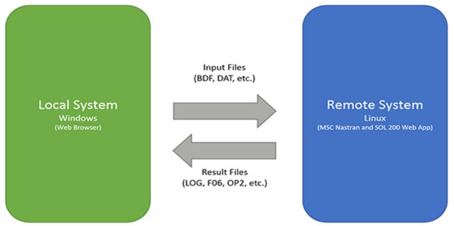
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



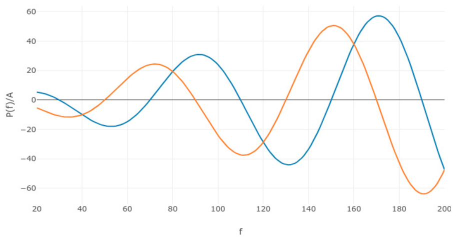
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



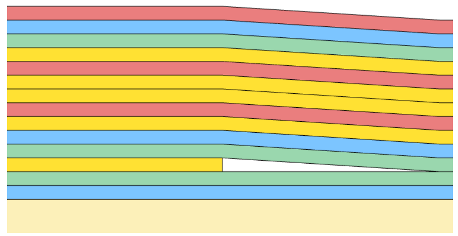
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



Dynamic Loads Web App
Generate RLOAD1, RLOAD2 and DLOAD entries graphically

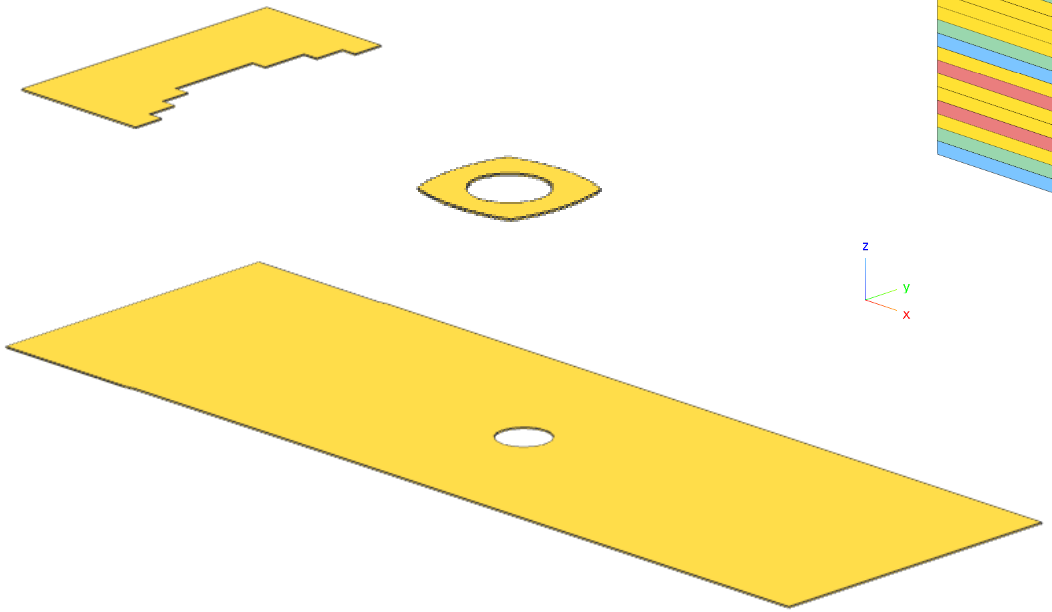


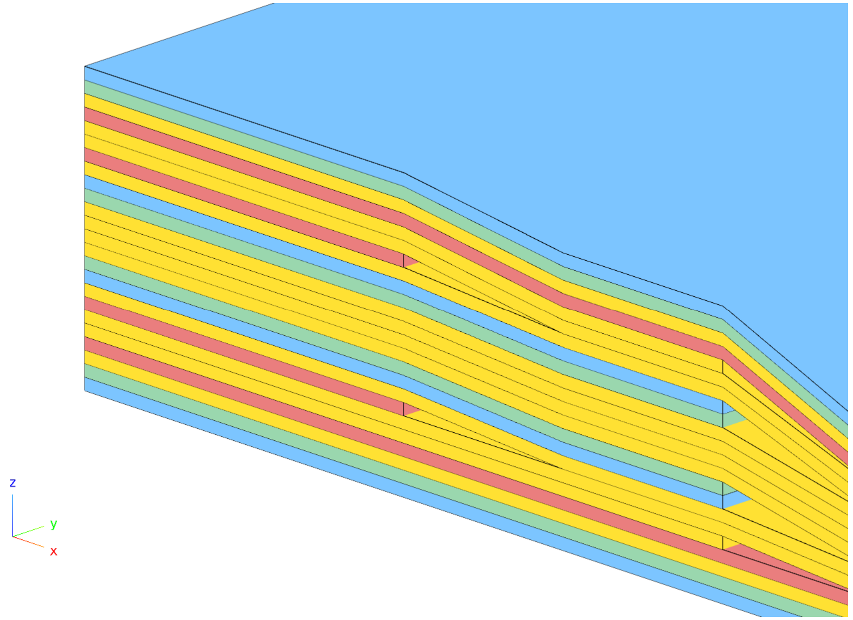
Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

Ply Shape (Drop-off) and Ply Number Optimization

Refer to the advanced tutorials for composite optimization

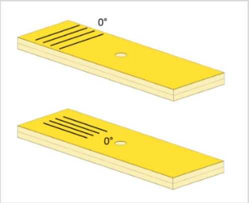
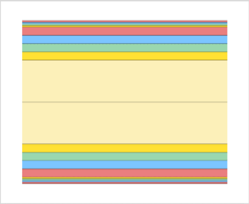
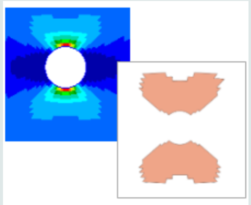




Before Continuing

Consider the New Composite Laminate Optimization Tutorials – Composite Coupon

Visit the User’s Guide to access the newest tutorials.

	Title and Description	PDF Tutorial	YouTube Tutorial
	**Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite** The goal of this 5-phase tutorial series is to optimize a composite coupon, with a core, and produce a lightweight composite that satisfies failure index constraints. The optimal ply shapes (ply drop-offs) and ply numbers are determined for 0°, ±45°, and 90° plies. A stacking sequence optimization is performed to satisfy manufacturing requirements. One important part of optimizing composites is visualizing the composite plies. This tutorial series also demonstrates the visualization of ply drop-offs, tapered plies and core layers. This first phase involves determining the optimal 0° direction of a composite. It is best practice to align the 0° plies in the direction of the load. Not doing so will more than likely produce a suboptimal composite that is heavier than necessary. This tutorial demonstrates the use of MSC Nastran's optimizer to determine the optimal 0° direction of a composite. An optimization is performed to maximize the stiffness of the composite for multiple load cases and while varying the angle of the 0° plies. Ultimately, the best 0° direction is determined. This is the first phase in a 5-phase tutorial series.	Link	Link
	**Composite Coupon – Phase B – Baseline Ply Number Optimization** This tutorial demonstrates how to configure a basic ply number optimization of continuous plies that span the entire model. The goal of this tutorial is to demonstrate basic actions such as creating variables, a weight objective and constraints on failure index. The results of this ply number optimization serve as a baseline for future comparisons. In a subsequent tutorial, the ply shapes will be optimized to minimize weight. This is the second phase in a 5-phase tutorial series.	Link	Link
	**Composite Coupon – Phase C – Data Preparation for Ply Shape Optimization** This tutorial is a guide to preparing data for ply shape optimization in a subsequent tutorial. The maximum failure index values of the outer plies of the composite are determined and saved to specially formatted PLY000i files. The PLY000i files will be used to construct optimal ply shapes in a subsequent tutorial. This is the third phase in a 5-phase tutorial series.	Link	Link

Before Continuing

Consider the New Composite Laminate Optimization Tutorials – Composite Coupon, Continued

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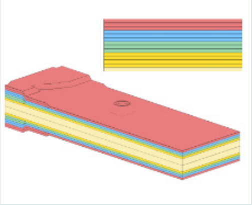
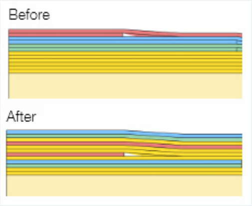
	Title and Description	PDF Tutorial	YouTube Tutorial
	**Composite Coupon – Phase D – Ply Shape and Ply Number Optimization** This tutorial details the process to build optimal ply shapes and perform a ply number optimization. The optimal ply shapes are constructed to follow the contours of the failure indices. The ply number optimization involves minimizing weight and constraining the failure indices of plies. The PLY000i files and BDF files from the previous tutorial, phase C, are used in this tutorial. This is the fourth phase in a 5-phase tutorial series.	Link	Link
	**Composite Coupon – Phase E – Stacking Sequence Optimization** This tutorial involves performing a stacking sequence optimization and is a continuation of the previous tutorial, phase D. A final statics analysis is performed to confirm the optimized composite satisfies failure index constraints. This is the fifth phase in a 5-phase tutorial series.	Link	Link

Before Continuing

Consider the New Composite Laminate Optimization Tutorials – Sandwich Composite Panel

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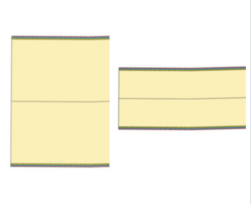
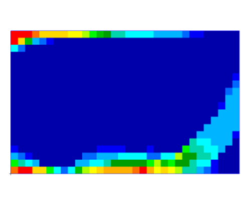
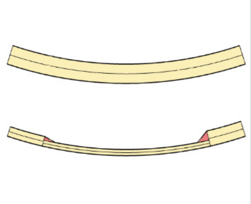
	Title and Description	PDF Tutorial	YouTube Tutorial
	**Sandwich Composite Panel – Phase B – Baseline Core Thickness Optimization** The goal of this 3-phase tutorial series is to optimize a curved composite panel, with a core, and produce a lightweight composite that satisfies constraints on the buckling load factor. This tutorial series focuses exclusively on optimizing the thickness of the core. The methods detailed in the tutorial series are applicable to both foam and honeycomb cores. This tutorial demonstrates how to configure a basic core thickness optimization where the core has a constant thickness throughout the entire model. The goal of this tutorial is to demonstrate basic actions such as creating variables, a weight objective and constraints on the buckling load factor. The results of this core thickness optimization serve as a baseline for future comparisons. In a subsequent tutorial, the core will be allowed to have a variable thickness throughout the model and will be optimized to minimize weight. This is the first phase in a 3-phase tutorial series.	Link	Link
	**Sandwich Composite Panel – Phase C – Topometry Optimization to Determine Optimal Core Shape** This tutorial is a guide to preparing data for core shape and core thickness optimization in a subsequent tutorial. A topometry optimization is performed in this tutorial to determine the ideal thickness distribution of the core throughout the entire composite panel while satisfying constraints on the buckling load factor and minimizing weight. The results of a topometry optimization are contained in the PLY000i files and will be used to construct optimal core shapes in a subsequent tutorial. This is the second phase in a 3-phase tutorial series.	Link	Link
	**Sandwich Composite Panel – Phase D – Core Shape and Core Thickness Optimization** This tutorial details the process to build optimal core shapes and perform a core thickness optimization. The optimal core shapes are constructed to follow the contours of thickness results generated by a topometry optimization. The core thickness optimization involves minimizing weight and constraining the buckling load factor. The PLY000i files and BDF files from the previous tutorial, phase C, are used in this tutorial. Comparisons are made between this optimization in phase D and the baseline optimization performed in phase B. This is the third phase in a 3-phase tutorial series.	Link	Link

Tutorial