## Workshop – Composite Coupon – Phase D – Ply Shape and Ply Number Optimization

AN MSC NASTRAN SOL 200 TUTORIAL



This workshop is phase D of a 5-phase workshop.

#### Phase A

Workshop – Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite

- Perform an optimization on the angle of ply 1 to maximize stiffness
- Tools Used: MSC Nastran and SOL 200 Web App

Phase B

Workshop – Composite Coupon – Phase B – Baseline Ply Number Optimization

- Perform a ply number optimization with full and continuous ply shapes
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

#### 0° Direction Optimization

#### **Baseline Ply Number Optimization**



This workshop is phase D of a 5-phase workshop.





This workshop is phase D of a 5-phase workshop.

Phase C	Phase D	Phase E
Workshop – Composite Coupon – Phase C – Data Preparation for Ply Shape	Workshop – Composite Coupon – Phase D – Ply Shape and Ply Number Optimization	Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization
<ul><li>Optimization</li><li>Manually create PLY000i Files</li></ul>	<ul> <li>Input BDF and PLY000i Files</li> <li>Create Ply Shapes</li> <li>Perform Ply Number Optimization</li> <li>Inspect Plies</li> </ul>	<ul> <li>Input BDF</li> <li>Perform Stacking Sequence Optimization</li> <li>Validate Performance</li> <li>Inspect Plies</li> </ul>
<ul> <li>Tools Used: Patran, MSC Nastran and SOL 200 Web App</li> </ul>	<ul> <li>Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran</li> </ul>	<ul> <li>Tools Used: SOL 200 Web App (Stacking Sequence and Viewer web apps) and MSC Nastran</li> </ul>
Ply S	hape Optimization Ply Number Optimization	Stacking Sequence Optimization



This workshop is phase D of a 5-phase workshop.





## Goal: Construct Optimal Ply Shapes and Perform Ply Number Optimization

- The goal is to construct ply shapes that produce a lightweight composite but satisfy failure index constraints.
- This tutorial discusses how to operate the Viewer web app to construct new optimized ply shapes and perform a ply number optimization.





## Details of the structural model



[90/+45/-45/0/90/+45/-45/0/0<sub>core</sub>]<sub>s</sub>



### Details of the Composite Layers

#### This composite consists of 18 layers.

The PCOMP entry defines only 9 layers, but the LAM=SYM option indicates that the composite is symmetric. Internally, layers 10, 11, ..., 18 are generated and stored.

- Layers 9 and 10 correspond to the core.
- These layers are NOT optimized.
  - Layers 1 and 18 correspond to 90° layers.
  - Layers 2 and 17 correspond to 45° layers.
  - Layers 3 and 16 correspond to -45° layers.
  - Layers 4 and 15 correspond 0° layers.
- These layers are optimized.
  - Layers 5 and 14 correspond to 90 ° layers.
  - Layers 6 and 13 correspond to 45° layers.
  - Layers 7 and 12 correspond to -45° layers.
  - Layers 8 and 11 correspond 0° layers.

					Layer 1 Layer 2 Layer 3 Layer 4 Layer 5 Layer 6 Layer 7 Layer 8
					Layer 9 Layer 10
					Layer 11 Layer 12 Layer 13 Layer 14 Layer 15 Layer 16 Layer 17 Layer 18
	+;	z_element			
PCOMP	1 101 101 101 101 101 101 101 501	.125 .125 .125 .125 .25 .25 .25 .25 .25 .25 .25 .175	90. 45. -45. 0. 90. 45. -45. 0.	90. YES Laye YES Laye YES Laye YES Laye YES Laye YES Laye YES Laye	HILL er 1 er 2 er 3 er 4 er 5 er 6 er 7 er 8 er 9



SYM



### Recommended PCOMP Sequence for Optimization

When following the optimization procedure documented in this tutorial, the initial PCOMP entry should meet the following 2 criteria.

#### 1. Include fixed and non-fixed layers

It is recommended that the PCOMP entry is formatted with fixed and non-fixed layers.

- The fixed layers will remain unchanged during the optimization procedure and their thicknesses are equal to the ply thickness. These layers are meant to track quantities such as ply stress, ply strain, failure index or strength ratio.
- The non-fixed layer's thicknesses will vary throughout the optimization procedure.

Consider the 90-degree layers. One 90-degree layer is placed as layers 1 and 5. Layer 1's thickness is fixed to .125mm. Layer 5's thickness will vary during the optimization procedure.

### 2. The sequence should have $90^\circ,$ then $0^\circ$ layers

The 90-degree layers should come before the 0-degree layers.

NOT OK: [0/+45/-45/90/0/+45/-45/90/ 0<sub>core</sub>]<sub>s</sub>

OK: [90/+45/-45/0/90/+45/-45/0/ 0<sub>core</sub>]<sub>s</sub>

					Layer 1	
					Layer 2	
					Layer 3	
					Layer 4	
					Layer 5	
					Layer 6	
					Layer 7	
					Layer 8	
					Lavor Q	
					Laver 10	
					Layer 10	
					Louise 11	
					Layer 11	
					Layer 12	
					Layer 13	
					Laver 15	
					Layer 16	
					Layer 17	
					Layer 18	
		+				
	+z_	_element				
PCOMP	1			90.	HILL	
	101	.125	90.	YES Lave	r 1 🗋	These plies remain fixed
	101	125	45		r 2	throughout the entire
	101	105	15.	VEC Lave		optimization procedure.
		.125	-45.	IES Laye		
	101	.125	0.	YES Laye	r 4	Create TOMVAR entries
	101	.25	90.	YES <mark>Laye</mark>	r 5 🗍	for the layers and
	101	.25	45.	YES <mark>Laye</mark>	r 6	perform ply shape and
	101	.25	-45.	YES Lave	r 7	ply number
	101	11   25   0   VEGLa			r 8	optimization for these
		• 4 J 0 1 7 E	0.	VEC Love		layers only
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					4	0.0N



Monitor the failure index of each layer or constrain the failure index with DRESP1/DCONSTR entries.

SYM



#### Using PLY000i Files to Create Optimal Ply Shapes

- The data contained in PLY000i files, e.g. model.ply0005, are critical to construct optimal ply shapes. BDF and PLY000i files are used in this tutorial to construct new optimal ply shapes.
- The SOL 200 Web App's Viewer is used to create new ply shapes.
- Ply shape candidates 1, 2 and 3 are used for the 90°, ±45° and 0° layers. Additional ply shapes can yield further mass reduction. For 0°, additional ply shape candidates 4 and 5 are created.
- Each ply shape candidate is assigned a unique GPLY ID, e.g. 111000, 2111000. For more details on the GPLY ID numbering convention, refer to the appendix, section GPLY ID Numbering Convention (sPLC00).
- Ply shapes are created based on the data contained in the PLY000 files. The PLY000i files are generated by Topometry Optimization or may be created manually, as done in this tutorial. Alternatively, both methods may be combined for a hybrid method.
- Some GPLY IDs have a number 2 as a suffix. This composite is symmetric and the suffix of 2 indicates a symmetric ply. For example, GPLY ID 151000 has a corresponding 2151000 mirror ply.

Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000	152000, 2152000	153000, 2153000		
			0		
6, 7	161000, 2161000	162000, 2162000	163000, 2163000		
±45°	171000, 2171000	172000, 2172000	173000, 2173000		
	•	0	• O		
8	181000 <i>,</i> 2181000	182000 <i>,</i> 2182000	183000 <i>,</i> 2183000	184000 <i>,</i> 2184000	185000 <i>,</i> 2185000
0°	•	•			
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Ply Shape

## **Optimization Problem Statement**





## More Information Available in the Appendix

## The Appendix includes information regarding the following:

- What filter values to use?
- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)
- Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading
- Optimizing Composite Ply Shapes and Numbers for Bending





### 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



# Tutorial



## **Tutorial Overview**

- 1. Part 1 Ply Shape Creation
- 2. Part 2 Ply Number Optimization
- 3. Part 3 View New Plies

#### **Special Topics Covered**

**Ply Shape Editing** - Ply shapes require the creation of multiple PCOMP/PCOMPG entries and assigning these entries to different 2D elements, e.g. CQUAD4, CTRIA3. This tutorial describes this procedure via the use of the SOL 200 Web App. Ultimately, optimal ply shapes are created.

**Ply Number Optimization** – Once the optimal ply shapes are constructed, a ply number optimization is performed.

**Ply Thickness Inspection** - The final plies may be visually inspected via the use of the Viewer web app.





## SOL 200 Web App Capabilities

#### Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge Installable on a company laptop, workstation or
- Windows and Red Hat Linux

server. All data remains within your company.

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

#### Benefits

entries.

- REAL TIME error detection. 200+
- error validations.
- REALT TIME creation of bulk data
- 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.



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



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



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



**PBMSECT Web App** Generate PBMSECT and PBRSECT entries graphically



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



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



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



browser on Windows and Linux



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



# Part 1 – Ply Shape Creation



## **Before Starting**

This tutorial is a continuation of the previous tutorial. You have two starting options.

- 1. You may continue on from the previous tutorial with the same BDF files.
- 2. Or you may start with prepared BDF files available in the User's Guide. Ensure the Downloads directory is empty in order to prevent confusion with other files. The next slides detail how to download prepared BDF files from the User's Guide.
- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran\_working\_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.





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## Go to the User's Guide

1. Click on the indicated link

• The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

#### Select a web app to begin Before After Optimization for SOL 200 Multi Model Optimization Machine Learning | Parameter HDF5 Explorer Viewer Study Tutorials and User's Guide (1)Full list of web apps

SOL 200 Web App



## Obtain Starting Files

- 1. Find the indicated example
- 2. Click Link
- 3. The starting file has been downloaded

• When starting the procedure, all the necessary BDF files must be collected together.



#### 1 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.

Starting BDF Files: Link 2 Solution BDF Files: Link





## Obtain Starting Files

- 1. Right click on the zip file
- 2. Select Extract All...
- B. Click Extract
- The starting files are now available in a folder
- This example is using a previously created design model. The design model is a model that has been converted to SOL 200 and contains bulk data entries describing the optimization problem statement, e.g. variables, objective and constraints.

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## Open the Correct Page

1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.





## Open the Viewer

- 1. Navigate to the Composites section
- 2. Click Viewer

SOL 200 Web App - List of Web Apps

### Beams



PBMSECT

## Composites

Pty	Twis (* )	OPLY ID
1	40	121001
2	-40	1210201
3	0	141000
4	30	111201
5	0	141802
6	90	112001
7		14/18/23
	45	121000
9	-45	10/002

#### Stacking Sequence





## Import BDF Files

- 1. Click File Upload
- 2. Click Select files
- Navigate to directory
   2\_topometry\_optimization
- 4. Select the indicated files
- 5. Click Open
- 6. Click Upload files





## Import PLY000i Files

- 1. Click Topometry
- Click Select files
- 3. Navigate to directory 3\_manual\_ply000i\_files
- Select the indicated files
- Click Open
- Click Upload files



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## Configure Ply Number Optimization

- 1. Click Ply Shapes
- 2. Use the scroll bar to navigate to different sections
- 3. Navigate to section Ply Number Optimization Configuration
- 4. Click Failure Index
- 5. Select only Failure Index(FP) for direct stresses/strains
- 6. Ensure only the following row is displayed: Failure Index(FP) for direct stresses/strain
- There are many additional responses that may be set as design constraints, including ply stresses, strains, and others.

Topometry	/						
Uplo	ad Ply00	00i Files	Select a PCOMP	Ply Shapes New E	intries Download		
III View F	COMPG	Zones					5.2
Ply N	umbe	er Optin	nization Con	figuration			
<b>ɛ<sub>i</sub></b> Maxi	mum Ply	y Strain	<b>7</b> <i>i</i> Maximum Ply Stree	ss <b>FI</b> Failure Index	SR Strength Ratio		
Response	e to Sho	ow		(4)	Recall the following:		(2)
Normal Normal Shear-' Shear-2 Shear a Major p Minor p Maxim	-1 -2 -2 ZZ 2Z rincipal rincipal index(F	r P) for direct s	stresses/strains	5	<ul> <li>FI &lt; 1.0 OK</li> <li>FI &lt; .95 OK (Recomm</li> <li>FI ≥ 1.0 NOT OK (FA)</li> </ul>	mended) AILURE)	
GPLY ID	Theta	Candidate	Ply Thickness	Initial Number of Plies		Failure Index	
111000	90°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
				6	Failure Index(FP) for direct	Lower	Lipper



## Configure Ply Number Optimization

- 1. Do NOT set a ply thickness for the fist 4 layers.
  - The first 4 layers correspond to the outer layers and should remain fixed during the optimization. Supplying a ply thickness will set the layer as a design variable. Do NOT set a ply thickness for the first 4 layers.

Topometry

2. For the first 4 layers' failure index, set the upper bound to .95

Upload Ply000i Files Ply Shapes Select a PCOMP New Entries Download View PCOMPG Zones 22 GPLY Initial Number of Ply Thickness ID Theta Candidate Plies Failure Index 90° 111000 1 Thickness of Ply .01 Upper Allowed Lower Allowed Response Limit Limit (1)Failure Index(FP) for direct .95 Lower stresses/strains 121000 45° 1 .01 L2 Allowed Thickness of Ply Upper Allowed Response Limit Failure Index(FP) for direct Lower .95 stresses/strains -45° 131000 1 Thickness of Ply .01 Upper Allowed Lower Allowed Limit Limit Response Failure Index(FP) for direct Lower .95 stresses/strains 141000 0° 1 Thickness of Ply .01 Upper Allowed Lower Allowed Response Limit Limit Failure Index(FP) for direct .95 Lower stresses/strains



## Configure Ply Number Optimization

- Scroll to the layer with GPLY ID 151000
- 2. For the first 4 layers, set the Ply Thickness to .125 mm
  - For GPLY ID 171000 (-45°), the ply thickness option is disabled.
     The -45° is dependent on the +45° layer. One ply number variable is required for both +45° and -45°.
- 3. For the indicated plies, set the upper bound to .95
- 4. The 9<sup>th</sup> layer (GPLY ID 191000) is the core. This core layer is not optimized, nor is a constraint created for the core.
- It should be noted that if desired, the thickness of the core may also be optimized as long as a TOMVAR entry is defined for the core layer and a PLY000i file is created for the core layer. For this example, if the core layer is to be optimized, TOMVAR entry for layer 9 should be created and a PLY0009 file should be available.

#### Topometry Upload Ply000i Files Select a PCOMP Ply Shapes New Entries Download Wiew PCOMPG Zones \*\* (1 151000 90° .125 .01 Upper Allowed Lower Allowed Limit Limit Response Failure Index(FP) for direct Lower .95 stresses/strains 2 161000 45° 1 .125 .01 Lower Allowed Upper Allowed Limit Response Limit Failure Index(FP) for direct Lower .95 3 stresses/strains 171000 -45° 1 Thickness of Plv .01 Upper Allowed Lower Allowed Limit Limit Response Failure Index(FP) for direct Lower .95 stresses/strains 1 181000 0° .01 .125 Lower Allowed Upper Allowed Limit Limit Response Failure Index(FP) for direct Lower .95 stresses/strains 191000 0° 1 Thickness of Ply .01 Lower Allowed Upper Allowed Limit Limit Response (3)



Lower

Upper

Failure Index(FP) for direct

stresses/strains

## Create Ply Shape Candidates

- 1. Navigate to section Ply Shape Candidates
- 2. Click +Options
- 3. Set the Slider Step Size to 0.01





### Create Ply Shape Candidates

- 1. Scroll to the following table
- Click the indicated plus (+) icon 2 times to create 2 ply shape candidates for the 90° layer.
- 3. Click the indicated plus (+) icon 2 times to create 2 ply shape candidates for the 45° layer. Since the -45° is linked to the +45° layer, two -45° are also created.
- Click the indicated plus (+) icon 4 times to create 4 ply shape candidates for the 0° layer.
- 5. Move the indicated Threshold Slider to a value of 0.47
- 6. Move the indicated Threshold Slider to a value of 0.21
- 7. Move the indicated Threshold Slider to a value of 0.03
- 8. Move the indicated Threshold Slider to a value of 0.02
- Values of 0.47 and .21 are used. Refer to the appendix, section *What filter values to use*, for a discussion on how these values were selected.

1											
Display Ply Shape	Include in PCOMPGs	GPLY ID	Ply	Candidate	Dependent On Ply	Theta	Action	Threshold Slider	Threshold	Pick Mode	Number of Elements
		111000	1	1		90°	Ð	•	0		2280
		121000	2	1		45°	+	•	0		2280
		131000	3	1	2	-45°	+	•	0		2280
		141000	4	1		0°	+	•	0		2280
		151000	5	1		90° (	2)+	•	0		2280
		152000	5	2		90°	×		0.47		238
	<b>Z</b>	153000	5	3		90°	×		0.47		152
		161000	6	1		45° (	3)+	•	0		2280
	<b>Z</b>	162000	6	2		45°	×		0.21		172
		163000	6	3		45°	×	<b></b>	0.21		152
		171000	7	1	6	-45°	Đ	•	0		2280
		172000	7	2	6	-45°	×		0.21		172
		173000	7	3	6	-45°	×		0.21		152
	<b></b>	181000	8	1		0° (4	4)+	•	0		2280
		182000	8	2		0°	×		0.03		139
		183000	8	3		0°	×		0.03		76
		184000	8	4		0°	×		0.02		329
		185000	8	5		0°	×	<b></b>	0.02		304
		191000	9	1		0°	Ð		0		2280



## Position the Model

- Click the indicated icon to minimize the width of the panel
- 2. Click Center Model
- 3. Click Fit Model
- L. Click Background Color
- 5. Click Front
- 6. Use the mouse scroll wheel to zoom out, and press and hold the right mouse button, and drag the mouse left ward to drag the model into view.
- 7. Mark the indicated checkbox to display the first ply shape
- 8. Click +Options to hide the options section

Main Danal		Topometry						
		III View PCC	MPG Zones				(1)	) 📰
Camera								
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Misc.		📲 Clean Ply	Shape					
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View		7		111000	90.	Ð		
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✓ Bottom Iso 1B	$\overline{}$		<	123000	45.	×		
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## Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

					Ply Shape
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 •	152000, 2152000	153000, 2153000 o		
6, 7 ±45°	161000, 2161000 171000, 2171000	162000, 2162000 172000, 2172000	163000, 2163000 173000, 2173000		
8 0°	181000, 2181000 •	182000, 2182000	183000, 2183000	184000, 2184000	185000, 2185000
Questions? Ema	il: christian@ the-ei	ngineering-lab.com	HEXAGON Technology Partner		32

### Ply Shape Editing: Candidate 2 for 90°





## Ply Shape Editing: Candidate 2 for 90°

The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot

### Maximum Failure Index



### Ply Shape Candidate 2





## Ply Shape Editing: 90°, Candidate 2

- 1. Click the indicated icon
- 2. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 3.
- Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
- 4. Click Clean Ply Shape



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Topometry

View PCOMPG Zones

Lean Ply Shape

(4)

Picking Sphere Radius (Real World Units)

(1

3 (2)

## Ply Shape Editing: Candidate 2 for 45°




### Ply Shape Editing: Candidate 2 for 45°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of +45° and -45° plies

#### Maximum Failure Index



#### Ply Shape Candidate 2





## Ply Shape Editing: Candidate 2 for 45°

- Click the indicated icon
- 2. A red sphere appears and moves with mouse cursor. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
- Click Clean Ply Shape





Topometry

View PCOMPG Zones

Ply Shape Candidates - PCOMP 1

3

Theta Action

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GPLY

ID

111000 90°

121000 45°

131000 -45°

141000 0°

151000 90°

152000 90°

153000 90°

161000 45°

(3)

Include in

PCOMPGs

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Picking Sphere Radius (Real World Units)

Threshold

Slider

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Mode

(1

-

### Ply Shape Editing: Candidate 2 for 0°



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## Ply Shape Editing: Candidate 2 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

#### Maximum Failure Index



#### Ply Shape Candidate 2





## Ply Shape Editing: Candidate 2 for 0°

- Click the indicated icon
- A red sphere appears and moves with mouse cursor. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
- Click Clean Ply Shape 3 times



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(1

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# Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

					Ply Shape
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 •	152000, 2152000	153000, 2153000		
6, 7 ±45°	161000, 2161000 171000, 2171000	162000, 2162000 172000, 2172000	163000, 2163000 173000, 2173000		
8 0°	181000, 2181000 •	182000, 2182000	183000, 2183000	184000, 2184000	185000, 2185000
Questions? Ema	il: christian@ the-er	ngineering-lab.com	HEXAGON Technology Partner		42

### Ply Shape Editing: Candidate 3 for 90°



Questions? Email: christian@ the-engineering-lab.com

Before



### Ply Shape Editing: Candidate 3 for 90°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- Below are possible candidate shapes. The shape in the bottom left follows the contours of the failure index but is difficult to manufacture. The shape in the bottom right is more manufacturable and overlaps the same region region.



#### Maximum Failure Index



#### Ply Shape Candidate 2



## Ply Shape Editing: 90°, Candidate 3

- 1. Click the indicated icon
- 2. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9.
- 3. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

		Topometry						
		III View PC	DMPG Zones	실 P disat	ick mode bled. Clicl	on. Mod k to exit	lel rotation pick mode.	23
3		<b>s</b> it Clean Ph	Shape	Pi	icking Sp	ohere Ra	idius (Real Wo	rld Units)
		+ Options Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
				111000	90°	+	•	
			<b></b>	121000	45°	+	•	
				131000	-45°	+	•	
			1	141000	0°	+	•	
			2	151000	90°	+	•	
			<b>~</b>	152000	90°	×		
				153000	90°	×		
Defere	Aftor		<b>1</b>	161000	45°	+	•	
Belore	Alter			162000	45°	×		
3			<b>~</b>	163000	45°	×		
							GPLY	



## Ply Shape Editing: 90°, Candidate 3

- 1. Use the scroll wheel on the mouse to zoom in to the hole
- 2. Click the indicated icon
- 3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.5.
- 4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

 If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.





III View PCO	MPG Zones	Zones 실 Pick mode on. Model rotation disabled. Click to exit pick mode.					
+ Options	Shape	Pi	cking S	3	adius (Real Wo	orld Units)	
Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode	
	1	111000	90°	+	•		
	1	121000	45°	+	•		
	<b>\$</b>	131000	-45°	+	•		
	s/	141000	0°	+	•		
	<b>V</b>	151000	90°	+	•		
	<b>2</b>	152000	90°	×			
		153000	90°	×		2	
	2	161000	45°	+	•		
		162000	45°	×			
	<b>~</b>	163000	45°	×			

Topometry





### Ply Shape Editing: Candidate 3 for 45°



Questions? Email: christian@ the-engineering-lab.com

Before



## Ply Shape Editing: Candidate 3 for 45°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of +45° and -45°

Maximum Failure Index



#### Ply Shape Candidate 2





## Ply Shape Editing: 45°, Candidate 3

- Click Fit Model to view the full model (not shown)
- 2. Click the indicated icon
- A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9.
- 4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.







## Ply Shape Editing: 45°, Candidate 3

- 1. Use the scroll wheel on the mouse to zoom in to the hole
- 2. Click the indicated icon
- A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.5.
- 4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

 If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.









### Ply Shape Editing: Candidate 3 for 0°



Questions? Email: christian@ the-engineering-lab.com



## Ply Shape Editing: Candidate 3 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

#### Maximum Failure Index



#### Ply Shape Candidate 2





## Ply Shape Editing: 0°, Candidate 3

- Click Fit Model to view the full model (not shown)
- 2. Click the indicated icon
- 3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9.
- 4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

		То	pometry						
			View PCON	IPG Zones	실 P disal	Pick mod bled. Cli	le on. Mo ck to exit	del rotation pick mode.	
4	$\bigcirc$	P 	Ply Sha	pe Cand	idates Pi	icking s	COMF	2 1 adius (Real Wo	orld Units)
			+ Options						
		Р	Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
				<b>V</b>	111000	90°	+	•	
				<b>S</b>	121000	45°	+	•	
				1	131000	-45°	÷	•	
				1	141000	0°	+	•	
				1	151000	90°	+	•	
-				<	152000	90°	×	-	
Before	After			<	153000	90°	×		
				<b>V</b>	161000	45°	+	•	
					162000	45°	×		
				<	163000	45°	×		
				<b>V</b>	171000	-45°	÷	•	
				1	172000	-45°	×		
				1	173000	-45°	×		
				1	181000	0°	+	•	
					182000	0°	×	-	
					183000	0°	×	-	
				<b>~</b>	18/000	0°			

Questions? Email: christian@ the-engineering-lab.com



## Ply Shape Editing: 0°, Candidate 3

- 1. Use the scroll wheel on the mouse to zoom in to the hole
- 2. Click the indicated icon
- 3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.2.
- 4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

 If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.





After

Topometry						
Wiew PCO	MPG Zones	신 P disat	ick mod bled. Cli	e on. Mo ck to exit	del rotation pick mode.	23
Ply Sha	pe Cand	idates	- PC	OMF	P 1	
📲 Clean Ply :	Shape	Pi	cking S	phere R	adius (Real Wo	orld Units)
			0.2 3	)		
+ Options						
Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
	1	111000	90°	÷	•	
		121000	45°	+	•	
		131000	-45°	+	•	
	1	141000	0°	+	•	
	1	151000	90°	+	•	
	<	152000	90°	×		
	<	153000	90°	×		
		161000	45°	+	•	
		162000	45°	×		
		163000	45°	×		
		171000	-45°	+	•	
		172000	-45°	×		
		173000	-45°	×		
		181000	0°	+	•	
		182000	0°	×		
		183000	0°	×		2
	<b>Z</b>	184000	0°	×		





# Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

					Ply Shape
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000	152000, 2152000	153000, 2153000 o		
6, 7 ±45°	161000, 2161000 171000, 2171000	162000, 2162000 172000, 2172000	163000, 2163000 173000, 2173000		
8 0°	181000, 2181000 •	182000, 2182000	183000, 2183000	184000, 2184000	185000, 2185000
Questions? Ema	ail: christian@ the-er	ngineering-lab.com			55

#### Ply Shape Editing: Candidate 4 for 0°



Questions? Email: christian@ the-engineering-lab.com



## Ply Shape Editing: Candidate 4 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

#### Maximum Failure Index



#### Ply Shape Candidate 2





## Ply Shape Editing: Candidate 4 for 0°

- Click Fit Model to view the full model (not shown)
- 2. Click the indicated icon
- 3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 3.
- 4. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
- 5. Click Clean Ply Shape

			+ Options			
			Display Ply Shape	Include in PCOMPGs	GPLY ID	The
					111000	90°
					121000	45°
					131000	-45°
	$\frown$			~	141000	0°
	4				151000	90°
				2	152000	90°
				<	153000	90°
				~	161000	45°
				<	162000	45°
				<b>~</b>	163000	45°
				~	171000	-45°
Deferre	۸ ft o r			~	172000	-45°
Before	Atter			~	173000	-45°
4				~	181000	0°
	$\frown$			<	182000	0°
	( )			<b>~</b>	183000	0°
					184000	0°
	$\sim$			<b>~</b>	185000	0°
		GPLY		~	191000	0°
		No GPLY				

Questions? Email: christian@ the-engineering-lab.com



Topometry

Wiew PCOMPG Zones

🔡 Clean Ply Shape

(5)

Picking Sphere Radius (Real World Units)

Threshold

Slider

Pick

Mode

1

2 💁

1

1

1

2

3 (3)

Theta Action

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+

×

+

×

+

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**C** 

#### Ply Shape Candidates Creation

The indicated ply shape candidates will be created

Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5	151000, 2151000	152000, 2152000	153000, 2153000	1	
90°	•	•	•		
6, 7	161000 <i>,</i> 2161000	162000 <i>,</i> 2162000	163000 <i>,</i> 2163000		
±45°	171000 <i>,</i> 2171000	172000 <i>,</i> 2172000	173000, 2173000		
	•	0	•		
8	181000, 2181000	182000, 2182000	183000, 2183000	184000, 2184000	185000, 2185000
0°	•	•		•	•
Questions? Fma	ail: christian@ the-er	gineering-lab com	HEXAGON		59

Ply Shape

#### Ply Shape Editing: Candidate 5 for 0°





## Ply Shape Editing: Candidate 5 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

#### Maximum Failure Index



#### Ply Shape Candidate 2



Questions? Email: christian@ the-engineering-lab.com



## Ply Shape Editing: 0°, Candidate 5

- Click Fit Model to view the full model (not shown)
- 2. Click the indicated icon
- 3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9.
- 4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

4		
4 Before	After	

Topometry						
III View PCO	MPG Zones	신 Pi disat	ick mod bled. Cli	e on. Moo ck to exit	del rotation pick mode.	X
III Clean Ply	Shape	Pi	cking S	phere Ra	adius (Real Wo	orld Units)
			9 (3	)		
+ Options						
Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
	<b>1</b>	111000	90°	+	•	
	<b>S</b>	121000	45°	+	•	
	1	131000	-45°	+	•	
	1	141000	0°	+	•	
	1	151000	90°	+	•	
	<	152000	90°	×		
	<	153000	90°	×		
	1	161000	45°	+	•	
	<	162000	45°	×		
	<	163000	45°	×		
	1	171000	-45°	+	•	
	<b>1</b>	172000	-45°	×		
	1	173000	-45°	×		
	<b>1</b>	181000	0°	+	•	
	<b>~</b>	182000	0°	×		
	<b>~</b>	183000	0°	×		
		184000	0°	×		
		185000	0°	×		



Questions? Email: christian@ the-engineering-lab.com



## Ply Shape Editing: 0°, Candidate 5

- L. Use the scroll wheel on the mouse to zoom in to the hole
- 2. Click the indicated icon
- A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 1.
- 4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

 If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.











# Ply Shape Consolidation

- 1. Use the mouse scroll wheel to zoom out
- 2. Click View PCOMPG Zones
- 3. Click the indicated icon to display the Ply Shape Consolidation section
- 4. Click Update Consolidation Information

 Refer to the appendix, section PCOMPG Zones, for more information regarding PCOMPG zones.



	PCOMPG Zo	nes			
	Ply Shape Co	onsolida	tion	3	Ē
4	LE Update Co	nsolidatior	n Information	0	
	Keep More Ply Shapes			Keep F Ply Sh	ewer apes
	Level: 1 Levels Availal <b>Legend</b>	ble: 4			
	PCOMPG ID	Color	Stack		
	2		[ 90 <sub>2</sub> , 45 <sub>2</sub> , - 0 <sub>Core</sub> ]s	45 <sub>2</sub> , 0 <sub>2</sub> ,	
	3		[ 90 <sub>3</sub> , 45 <sub>3</sub> , - 0 <sub>Core</sub> ]s	45 <sub>3</sub> , 0 <sub>4</sub> ,	
	4		[ 90 <sub>3</sub> , 45 <sub>3</sub> , - 0 <sub>Core</sub> ]s	-45 <sub>3</sub> , 0 <sub>3</sub> ,	
	5		[ 90 <sub>3</sub> , 45 <sub>2</sub> , - 0 <sub>Core</sub> ]s	-45 <sub>2</sub> , 0 <sub>3</sub> ,	
	6		[ 90 <sub>2</sub> , 45 <sub>2</sub> , - 0 <sub>Core</sub> ]s	45 <sub>2</sub> , 0 <sub>3</sub> ,	
	7		[ 90 <sub>2</sub> , 45 <sub>2</sub> , - 0 <sub>Core</sub> ]s	45 <sub>2</sub> , 0 <sub>3</sub> ,	
	8		[ 90 <sub>3</sub> , 45 <sub>3</sub> , - 0 <sub>Core</sub> ]s	45 <sub>3</sub> , 0 <sub>3</sub> ,	



#### Ply Shape Candidates - PCOMP 1

E Clean Ply Shape

#### + Options

Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
		111000	90°	+	•	
	1	121000	45°	+	•	
	1	131000	-45°	+	•	
		141000	0°	+	•	
	<b>1</b>	151000	90°	+	•	
	<b>~</b>	152000	90°	×		
	<b>2</b>	153000	90°	×		2
	<b>1</b>	161000	45°	+	•	
	<b>2</b>	162000	45°	×		
	<b>2</b>	163000	45°	×		/
	<b>1</b>	171000	-45°	+	•	
	1	172000	-45°	×		
	2	173000	-45°	×		
	<b>1</b>	181000	0°	+	•	
_	-			-	_	



[ 903, 453, -453, 04,

O<sub>Core</sub>]s

9

# Ply Shape Consolidation

- 1. Move the slider to level 4
- 2. Note that the slider controls which checkboxes are marked. These checkboxes indicate which ply shapes are included in the final composite (PCOMPG entries).
- 3. The model is updated with different PCOMPG zones.

'ly Shape C	onsolida	tion	
JE Update Co	onsolidatior	n Information	
leep More Ny Shapes		Keep Fewe Ply Shapes	r
evel: 4		(	1)
evels Availa	ible: 4		_
evels Availa egend PCOMPG ID	Color	Stack	
evels Availa egend PCOMPG ID	Color	<b>Stack</b> [ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>2</sub> , 0 <sub>Core</sub> ]s	
evels Availa egend PCOMPG ID 2 3	Color	Stack [ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>2</sub> , 0 <sub>Core</sub> ]s [ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>3</sub> , 0 <sub>Core</sub> ]s	

+ Options						
Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
		111000	90°	+	•	
	1	121000	45°	+	•	
		131000	-45°	+	•	
		141000	0°	+	•	
		151000	90°	+	•	
		152000	90°	×		
$\mathcal{C}$		153000	90°	×		
		161000	45°	+	•	
		162000	45°	×		
		163000	45°	×		
		171000	-45°	+	•	
		172000	-45°	×		
		173000	-45°	×		
		181000	0°	+	•	
		182000	0°	×		
		183000	0°	×	-	/ 9
		184000	0°	×		
		185000	0°	×		/ 9
		191000	0°	+	•	



# Ply Shape Consolidation

- 1. Move the slider back to level 1
- 2. Note all the checkboxes are marked and will be included in the final PCOMPG entries
- Ensure the PCOMPG zones are similar to what is shown
- 4. Click the indicated icon



PCOMPG Zo	nes					
Ply Shape Consolidation						
Ji Update Co	onsolidatior	Information				
Keep More Ply Shapes		Keep Few Ply Shape				
Level: 1 Levels Availa <b>Legend</b>	ble: 4					
PCOMPG ID	Color	Stack				
2		[ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>2</sub> , 0 <sub>Core</sub> ] <sub>S</sub>				
3		[ 90 <sub>3</sub> , 45 <sub>3</sub> , -45 <sub>3</sub> , 0 <sub>4</sub> , 0 <sub>Core</sub> ] <sub>S</sub>				
4		[ 90 <sub>3</sub> , 45 <sub>3</sub> , -45 <sub>3</sub> , 0 <sub>3</sub> , 0 <sub>Core</sub> ] <sub>S</sub>				
5		[ 90 <sub>3</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>3</sub> ,				
		CoreJS				
6		[ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>3</sub> , 0 <sub>Core</sub> ]s				
6		0 CoreJS [ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>3</sub> , 0 CoreJS [ 90 <sub>2</sub> , 45 <sub>2</sub> , -45 <sub>2</sub> , 0 <sub>3</sub> , 0 CoreJS				
6 7 8		0 CoreJS [ 902, 452, -452, 03, 0 CoreJS [ 902, 452, -452, 03, 0 CoreJS [ 903, 453, -453, 03, 0 CoreJS				

.

Topometry View PCOMPG Zones + Uptions GPLY Threshold Display Include in Pick Ply Shape PCOMPGs ID Theta Action Slider Mode -111000 90° + 121000 45° + 131000 -45° + 141000 0° 151000 909 + 152000 90° 1 4 < 153000 909 1 2 ~ 161000 45° ~ 162000 45° ~ 163000 45° 171000 -45° ~ 172000 -45° 173000 -45° 2  $\checkmark$ 181000 0° 182000 0° 1 4 ✓ 183000 0° 1 • 184000 0° 1 2 185000 0° 1 9 + 191000 0° 



- 1. Click View PCOMPG Zones to hide the PCOMPG Zones window
- 2. Navigate to section Ply Number Optimization Configuration

Topometry					
Upload Ply000i Files	Select a PCOMP	Ply Shapes New E	ntries Download		
Wiew PCOMPG Zones					
Ply Number Opt	imization Confi	guration			
Ply Number Opt	Imization Confi	guration			
Ply Number Opt <i>E</i> i Maximum Ply Strain		<b>FI</b> Failure Index	SR Strength Ratio		
Ply Number Opt <i>E<sub>i</sub></i> Maximum Ply Strain Response to Show	Imization Confi $\sigma_i$ Maximum Ply Stress	<b>FI</b> Failure Index	SR Strength Ratio		
Ply Number Opt <i>E<sub>i</sub></i> Maximum Ply Strain Response to Show Normal-1	imization Confi σ <sub>i</sub> Maximum Ply Stress	<b>FI</b> Failure Index	SR Strength Ratio Recall the following: • FI < 1.0 OK		
Ply Number Opt <i>E</i> <sub>i</sub> Maximum Ply Strain Response to Show Normal-1 Normal-2 Shear-12	imization Confi σ <sub>i</sub> Maximum Ply Stress	<b>FI</b> Failure Index	SR Strength Ratio Recall the following: • FI < 1.0 OK • FI < .95 OK (	Recommended)	
Ply Number Opt ε <sub>i</sub> Maximum Ply Strain Response to Show Normal-1 Normal-2 Shear-12 Shear-12	α <sub>i</sub> Maximum Ply Stress	<b>FI</b> Failure Index	SR Strength Ratio     Recall the following:     • FI < 1.0 OK	Recommended) OK (FAILURE)	



- 1. Ensure the ply thickness is blank for the outer plies
- 2. For the indicated rows, ensure the upper bound of the failure index is set to .95

GPLY ID	Theta	Candidate	Ply Thickness	Initial Number of Plies	F	Failure Index	
111000	90°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
		1			Failure Index(FP) for direct stresses/strains	Lower	.95
						2	
121000	45°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
					Failure Index(FP) for direct stresses/strains	Lower	.95
131000	-45°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
					Failure Index(FP) for direct stresses/strains	Lower	.95
141000	0°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
					Failure Index(FP) for direct stresses/strains	Lower	.95
151000	90°	1	.125	.01	B	Lower Allowed	Upper Allowed



Do the following for ply shape candidates with GPLY ID: 151000, 152000, 153000, 161000, 162000, 163000, 171000, 172000, 173000, 181000, 182000, 183000, 184000, 185000 (rows 5-18 of the table)

- 1. For the indicated rows, ensure the ply thickness is set to .125 mm
- 2. For the indicated rows, ensure the upper bound of the failure index is set to .95
- The ply thickness is not necessary for the -45° layers because the -45° layers are linked to the +45° layers (not shown). During the ply number optimization, one ply number variable controls the +45° and -45° plies.

				N	·		
151000	90°	1	.125	.01	Response	Lower Allowed Limit	Upper Allowed Limit
					Failure Index(FP) for direct stresses/strains	Lower	.95
						(2)	
152000	90°	2	.125	.01	Response	Lower Allowed Limit	Upper Allowed Limit
					Failure Index(FP) for direct stresses/strains	Lower	.95
184000	0°	4	.125	.01	Response Failure Index(FP) for direct stresses/strains	Lower Allowed Limit	Upper Allowed Limit
185000	0°	5	.125	.01	Response	Lower Allowed Limit	Upper Allowed Limit
				)	Failure Index(FP) for direct stresses/strains	Lower	.95
191000	0°	1	Thickness of Ply	.01		Lower Allowed	Upper Allowed



1. Recall the core is neither optimized, nor constrained. The input boxes for the core are left blank.

0°	5	.125	.01	Response	Lower Allowed Limit	Upper Allowed Limit
				Failure Index(FP) for direct stresses/strains	Lower	.95
0°	1	Thickness of Ply	.01	Response	Lower Allowed Limit	Upper Allowed Limit
				Failure Index(FP) for direct stresses/strains	Lower	Upper
	0°	0° 5 0° 1	0°   5   .125     0°   1   Thickness of Ply	0°   5   .125   .01     0°   1   Thickness of Ply   .01	0°5.125.01Response0°1Thickness of Ply.01Response0°1Thickness of Ply.01ResponseFailure Index(FP) for direct stresses/strainsResponseFailure Index(FP) for direct stresses/strainsResponse	0° 5 .125 .01 Response Lower Allowed Limit   Failure Index(FP) for direct stresses/strains Lower Lower Lower   0° 1 Thickness of Ply .01 Response Lower Allowed   1 Thickness of Ply .01 Response Lower Allowed   Limit .01 Response Lower   Lower .01 Response Lower



# Consider Additional Optimization Options

1. Scroll to section Additional Optimization Options. There are additional options to adjust the ply number optimization.

Refer to the appendix for more information about these options.

Topometry						
Upload Ply000i Files	Select a PCOMP	Ply Shapes	New Entries	Download		
Wiew PCOMPG Zones						\$2 23
Additional Optimization	n Options 🕛					
Z0 Offset Relationship		% Rule Desig	gn		Total Thickness	

#### % Rule Design

 $\sim$ 

Theta [0]	% Lower Allowed Limit	% Upper Allowed Limit
90.	Lower	Upper
45.	Lower	Upper
-45.	Lower	Upper
0.	Lower	Upper

#### Total Thickness

Lower

Lower Allowed Limit	Upper Allowed Limit

Upper

Default

thickness of all layers.

Distance from the reference plane to the bottom

Default: -0.5 times the element thickness

 Above: 0.0 times the element thickness · Below: -1.0 times the element thickness

surface. The element thickness is the total



## Save New Entries

(1)

3

- 1. Navigate to section Respective PCOMP/PCOMPG Entries
- 2. The newest entries are displayed. There are approximately 8 new PCOMPG entries (PCOMPG 2-9) and multiple SOL 200 entries (DESVAR, DVPREL1, etc.)
- 3. Click Save New Entries
- 4. A checkbox confirm the entries has been saved.

Always be sure to click Save New Entries to commit any changes to the final downloaded BDF files.

Topometry				
Upload Ply000i Files Select a	PCOMP Ply Shapes	New Entries	Download	
Respective PCOMP/PC	COMPG Entries			5.2 2 3
Laminate Option SYM ✓ Ply Number Optimization Checklist ✓ Ply Thickness Ø Z0 Offset Ø % Rule Design Ø Total Thickness ✓ Constraints Markov Sectors ✓ 20	\$ 1    2    3   PCOMPG 2 111000 101   121000 101 131000 101   131000 101 141000 101   151000 101 161000 101   161000 101 161000 101   191000 501 2191000 501   2191000 501 2191000 101   2151000 101 2151000 101   2131000 101 2131000 101   2111000 101 2111000 101   2121000 101 2121000 101   2121000 101 2121000 101   2121000 101 2121000 101   2121000 101 2121000 101   2121000 101 121000 101	4 5   90.   125 90.   .125 45.   .125 -45.   .125 0.   1.00000 90.   1.00000 45.   1.00000 -45.   1.00000 0.   3.175 0.   1.00000 45.   1.00000 45.   1.00000 0.   1.00000 0.   1.00000 90.   .125 0.   .125 90.   .125 90.   .125 90.   .125 45.	I 6 I 7 II 8 II 9 II 10 I   HILL YES <td< th=""><th></th></td<>	
	131000 101 141000 101 151000 101 152000 101 161000 101 162000 101	.125 -45. .125 0. 1.00000 90. 1.00000 90. 1.00000 45. 1.00000 45.	YES YES YES YES YES	


# Save New Entries

1. Click New Entries

2. All the newest bulk data entries are displayed. These entries will be added to the downloaded BDF files.

Uploa	ad Ply000	i Files	Selecta	a PCOM	IP Ply Shapes New Entries Download
					(1)
_					
ew E	Intrie	S			
tries o	riginating	from PC	OMP 1		
1					
COMPG	2	>	1 4	90.	
	-	101	.125	90.	YES (2)
	121000	101	.125	45.	YES
	131000	101	.125	-45.	YES
	141000	101	.125	0.	YES
	151000	101	1.00000	90.	YES
	161000	101	1.00000	45.	YES
	171000	101	1.00000	-45.	YES
	181000	101	1.00000	0.	YES
	191000	501	3.175	0.	YES
	2191000	501	3.175	0.	YES
	2181000	101	1.00000	0.	YES
	2171000	101	1.00000	-45.	YES
	2161000	101	1.00000	45.	YES
	2151000	101	1.00000	90.	YES
	2131000	101	125	-45	VES
	2121000	101	.125	45.	YES
	2111000	101	.125	90.	YES
COMPG	3			90.	HILL
	111000	101	.125	90.	YES
	121000	101	.125	45.	YES
	131000	101	.125	-45.	YES
	141000	101	.125	0.	YES
	151000	101	1.00000	90.	YES



# Consideration for Multiple PCOMPs

- 1. Click Select a PCOMP
- 2. If TOMVAR entries were defined for multiple PCOMP entries, ply shapes may be defined for each PCOMP. Use the Select a PCOMP section to switch between the different PCOMPs.

- Optimal ply shapes may be constructed for other layers in different PCOMPs as long as the following conditions are met.
  - 1. A TOMVAR entry is created for that layer
  - 2. A PLY000i file is created for that layer

Topometry
Upload Ply000i Files Select a PCOMP Ply Shapes New Entries Download
Select a PCOMP
Only PCOMP entries referenced by TOMVAR entries with PNAME=Ti are listed.



# Download

- 1. Click Download
- 2. Click Download BDF Files
- 3. A reminder is displayed. The downloaded BDF files require additional configuration. Click the indicated link to open the Optimization web app.

Upload Ply000i Files	Select a PCOMP Ply Shapes New Entries Download						
Download							
	Download BDF Files     2     Compressing: 100%						
Compressing: 100% Last Item Compressed: design_pcompgs.bdf							
	<ul> <li>Reminder! Upload the new BDF files to the Optimization web app to and do the following.</li> <li>Update the objective and constraints</li> <li>Assign constraints to subcases</li> <li>Inspect design model for any errors</li> </ul>						



# Rename ZIP File

- 1. A new ZIP file has been downloaded
- 2. Rename the downloaded ZIP file to 4\_ply\_shape\_output.zip





# Part 2 – Ply Number Optimization



# Extract the ZIP File

- 1. Right click on the ZIP file and click Extract All
- 2. Click Extract
- 3. A new folder with the new BDF files has been created



×

Browse...

Extract Cancel

2

# Upload BDF Files

- 1. Switch to the Optimization web app
- Click Select files
- 3. Navigate to directory 4\_ply\_shape\_output
- 4. Select the indicated files
- 5. Click Open
- 6. Click Upload files

Step 1 - Upload .BDF Files		
2   1. Select files   3 files select	ed	
	Inspecting: 100%	
6 2. Upload files	Open	Search 4_ply_shape_output
	Organize 🔻 New folder	ii - 🗋 🔞
List of Selected Files	Favorites     Name       Desktop     design_model.bdf       Downloads     design_pcompgs.bdf       Recent Places     model.bdf	Date modified         Type           4/4/2023 2:23 PM         Notepad+           4/4/2023 2:23 PM         Notepad+           4/4/2023 2:23 PM         Notepad+
	<ul> <li>□ Libraries</li> <li>□ Documents</li> <li>□ Music</li> <li>□ Pictures</li> <li>□ Videos</li> </ul>	
	File name: "design_model.bdf" "design_pcon	✓ Custom Files (*.bdf;*.dat;*.inc;* ▼     ✓     Open ▼ Cancel
Questions? Email: christian@ the-engineering	z-lah.com	79

Technology Partner

(1)

SOL 200 Web App - Optimization

Upload

Variables

Objective

Constraints



Results

Exporter

Subcases

# Variables

- 1. Click Variables
- 2. Navigate to section Step 4 Adjust design variables
- 3. Click the indicated icon 3 times to expand the width of the variables section
- 4. Click +Options
- 5. Mark the checkbox for Label Comments
- 6. Click 20 to display at most 20 rows in the table
- 7. All the ply number variables are displayed
- When defining new ply shapes in the Viewer web app, a ply thickness was defined. By providing ply thickness values, ply number variables have been automatically created. On this page, those ply number variables are inspected.
- From experience, it has been found that if the initial number of plies is high, e.g. 60, 50 or 40 plies, the optimization converges to a sub-optimal solution. If the initial number of plies starts at a very fractional values, e.g. 0.01 plies, the converged solution is more optimal.
- The ply number variables (y1, y2, ..., y11) will take on discrete values of 1, 2, 3, 4, etc. Also, small fractional values are purposely used to determine negligible plies.

SOL 200 Web App - Optimization	Dad Variables Objective Constraints Subcases Exporter Results	Settings Match Other	User's Guide Home
Size Topology Topometry Topogra Step 4 - Adjust design va	riables 2		BDF 3
+ Options 4		+ Create Variable	Output - Design Model
CSV Export	CSV Import	mport	\$ \$ \$ \$

	Label ‡	Status 💠	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values	Label Comments
	Search	Search					
×	у1	0	.01	.0001	100.0		Parent PCOMP 1 - Number of plies for 90*, GPLY IDs: 151000, 2151000
×	y2	0	.01	.0001	100.0		Parent PCOMP 1 - Number of plies for 90*, GPLY IDs: 152000, 2152000
×	уЗ	0	.01	.0001	100.0		Parent PCOMP 1 - Number of plies for 90°, GPLY IDs: 153000, 2153000
×	y4	0	.01	.0001	100.0		Parent PCOMP 1 - Number of plies for 45*, GPLY IDs: 161000, 171000, 2171000, 2161000
×	y5	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 45*, GPLY IDs: 162000, 172000, 2172000, 2162000
×	уб	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, 7 RU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 45°, GPLY IDs: 163000, 173000, 2173000, 2163000
×	у7	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 0*, GPLY IDs: 181000, 2181000
×	у8	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 0*, GPLY IDs: 182000, 2182000
×	у9	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 0*, GPLY IDs: 183000, 2183000
×	y10	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 0*, GPLY IDs: 184000, 2184000
×	y11	0	.01	.0001	100.0	.01, .02, .03, .04, .05, .06, .07, .08, .09, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0, THRU, 100.0, BY, 1.0	Parent PCOMP 1 - Number of plies for 0°, GPLY IDs: 185000, 2185000





s s

# Objective

- 1. Click Objective
- 2. Click the indicated icon 3 times to minimize the width of the objective section
- 3. The weight is already set as an objective

• The objective was previously defined in the BDF files when the TOMVAR entries were defined. The weight objective is left as is.

SOL 101 - Static	5 5		× \$	Design	Objective	
elect a respons	e		\$ DRESP1 8000000 r0	WEIGHT	3 3	
	Response Description $\Rightarrow$	Response Type 💠				
	Search	Search				
+	Weight	WEIGHT				
+	Volume	VOLUME				
+	Displacement	DISP				
•	Strain	STRAIN				
+	Element Strain Energy	ESE				
« 1 2	3 4 5 »	5 10 20 30 40 50	50			



# Constraints

- 1. Click Constraints
- 2. Navigate to section Step 2 Adjust
- 3. Click 10 to display at most 10 rows in the table
- 4. The design constraints on failure index are displayed

• When defining new ply shapes in the Viewer web app, an upper bound on the failure indices was specified and corresponding DRESP1/DCONSTR entries were created. These design constraints are inspected on this page.

onstra	ints	Equa	ation Constrain	nts	1	)								
ep 2	2 - A	Adjus	st constra	aints 2	Ğ					BDF Output	- Design Mo	del		
ption	s									\$ \$	Design Con	straints		
Lal	pel s	Status ≑	Response Type ≑	Property Type	ATTA 🗘	ATTB ≑	ATTI ≑	Lower Allowed Limit	Upper Allowed Limit	\$\$ \$ \$ DRESP1 8000001 r1	CFAILUREPCOMPG	5	111000 2	
s		Seai	Search	Search	Search	Search	Search	Search	Search	DRESP1 8000003 r3 DRESP1 8000004 r4 DRESP1 8000004 r5	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5	111000 4 111000 5 111000 5	
r1		0	CFAILURE	PCOMPG 🗸	5 - Failure Index(FP) for direct stre: 🗸	111000	2	Lower	.95	DRESP1 8000006 r6 DRESP1 8000007 r7 DRESP1 8000008 r8	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5 5	111000 7 121000 2 121000 3	
r2		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre: 🗸	111000	3	Lower	.95	DRESP1 8000009 r9 DRESP1 8000010 r10 DRESP1 8000010 r10	CFAILUREPCOMPG CFAILUREPCOMPG	5	121000 4 121000 5	
r3		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre: V	111000	4 (4)	Lower	.95	DRESP1 8000012 r12 DRESP1 8000013 r13	CFAILUREPCOMPG	5	121000 7 121000 2	
r4		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre:	111000	5	Lower	.95	DRESP1 8000014 114 DRESP1 8000015 115 DRESP1 8000016 116	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5	131000 4 131000 5	
r5		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre: V	111000	6	Lower	.95	DRESP1 8000017 r17 DRESP1 8000018 r18 DRESP1 8000019 r19	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5	131000 6 131000 7 141000 2	
r6		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre:	111000	7	Lower	.95	DRESP1 8000020 r20 DRESP1 8000021 r21 DRESP1 8000022 r22	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5	141000 3 141000 4 141000 5	
r8		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre:	121000	3	Lower	.95	DRESP1 8000023 r23 DRESP1 8000024 r24 DRESP1 8000025 r25	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5 5	141000 6 141000 7 151000 2	
r9		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre: 🗸	121000	4	Lower	.95	DRESP1 8000026 r26 DRESP1 8000027 r27 DRESP1 8000028 r28	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5 5	151000 3 151000 4 151000 5	
r10		0	CFAILURE	PCOMPG V	5 - Failure Index(FP) for direct stre:	121000	5	Lower	.95	DRESP1 8000029 r29 DRESP1 8000030 r30 DRESP1 8000031 r31	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5 5	151000 6 151000 7 152000 4	
1	2	3	4 5 6	7 13	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			5 10 20 30	0 40 50	DRESP1 8000032 r32 DRESP1 8000033 r33 DRESP1 8000034 r34	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5 5 5	153000 6 153000 7 161000 2	
	~	Ŭ						3		DRESP1 8000035 r35 DRESP1 8000036 r36 DRESP1 8000036 r37	CFAILUREPCOMPG CFAILUREPCOMPG CFAILUREPCOMPG	5	161000 3 161000 4 161000 5	
										DRESF1 0000037 157	C. ALCOREFCONFG	2	101000 3	



161000 6

DRESP1 8000038 r38 CFAILUREPCOMPG

# Subcases

- 1. Click Subcases
- 2. Select only SUBCASE 1 and 2
- 3. Click 200 to display at most 200 rows in the table
- 1. Click Check visible boxes
- 5. All the failure index constraints have been assigned to subcase 1 and 2.
- The Viewer web app automatically created ply number variables and constraints on the failure indices. The optimization web app is used to assigned the constraints to different subcases, as shown on this page.

netrainte					
1 2					
(2)					
				I Uncheck visible bo	xes Check v
tus	Response				
Label \$	Туре	Description	SUBCASE 1 🌲	SUBCASE 2 \$	
Search	Search	Search			
r1	CFAILURE	Failure Index(FP) for direct stresses/strains of elements associated with PCOMPG 2 for lamina			5
		Foilure Index/FD) for direct stresses/strains of			
t	2 2 US Label \$ Search	2 2 2 2 2 2 2 2 2 2 2 2 2 2	Image: Search     Response Type     Description       Search     Search     Search       Image: Search     Search     Search	2         us       Label \$       Response Type \$       Description       SuBCASE 1 \$         Search       Search       Search       Search       Image: Subcase of the search of th	2         us       Label ‡       Response Type *       Description       SUBCASE 1 ‡       SUBCASE 2 ‡         Search       Search       Search       Search       Image: Subcase 2 ‡         1       CFAILURE       Failure Index(FP) for direct stresses/strains of elements associated with PCOMPG 2 for lamina       Image: Subcase 2 ‡

10 25 50 100 200 3



### Optimization Settings

### BDF Output - Design Model

# Settings

- 1. Click Settings
- 2. Set the maximum number of design cycles to 60
- 3. Set P2 to 15 Print objective, design variables, ...

 The P2 option is used for debugging optimizations. If a topometry optimization is performed, a P2 setting equal to 15 will yield a lot of variable information in the F06 file. When defining the original BDF files with TOMVAR entries, P2 was automatically set to 12, so as to leave out variable information from the F06 file. On this page, the P2 option is set back to 15 which will include the design variable information in the F06 file.

Parameter 💠	Description 🗢	Configure  \$ S Optimization Control Settings
Search	Search	Search S
APRCOD	Approximation method to be used	2 - Mixed Method
CONV1	Relative criterion to detect convergence	Enter a positive real number \$ Parameter to create the H5 result file. Supported in MSC Nastran 2016.1 or newer.
CONV2	Absolute criterion to detect convergence	Enter a positive real number         MDLPRM         HDF5         2
DELX	Fractional change allowed in each design variable during any optimization cycle	Enter a positive real number
DESMAX	Maximum number of design cycles to be performed	☑ 60
DISBEG	Design cycle number for discrete variable processing initiation	Enter a positive integer
GMAX	Maximum constraint violation allowed at the converged optimum	Enter a positive real number
P1	Print items, e.g. objective, design variables, at every n-th design cycle to the .f06 file	
P2	Items to be printed to the .f06 file	15 - Print objective, design variab V
TCHECK	Topology Checkerboarding	-1 - Automatic selection (Default)
TDMIN	Minimum diameter of members in topology optimization	Enter a positive real number
TREGION	Trust Region	1 - Trust Region On



5 10 20 30 40 50

SOL 200 Web App - Optimization Upload Variables Objective Constraints Subcases Exporter Results

### BDF Output - Model

Export New BDF Files

1. Click on Exporter

2. Click on Download BDF Files

 When the download button is clicked a new file named "nastran\_working\_directory" is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. "nastran\_working\_directory (1).zip"

assign userfile = 'optimization\_results.csv', status = unknown, form = formatted, unit = 52 \$ MSC.Nastran input file created on March 08, 2023 at 12:46:53 by \$ Patran 2022.2 \$ Direct Text Input for Nastran System Cell Section \$ Direct Text Input for File Management Section \$ Direct Text Input for Executive Control \$ Linear Static Analysis, Database SOL 200 CEND \$ Direct Text Input for Global Case Control Data ECHO = NONE DESOBJ(MIN) = 8000000 \$ DESGLB Slot \$ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL SUBCASE 1 ANALYSIS = STATICS DESSUB = 40000001 \$ DRSPAN Slot SUBTITLE=Load Case 1 SPC = 2LOAD = 2DISPLACEMENT(PLOT, SORT1, REAL)=ALL SPCFORCES(PLOT, SORT1, REAL)=ALL STRESS(PLOT, SORT1, REAL, VONMISES, BILIN)=ALL \$ Direct Text Input for this Subcase SUBCASE 2 ANALYSIS = STATICS

### Download BDF Files

Download BDF Files
 2



1

# Rename ZIP File

- 1. A new ZIP file has been downloaded
- 2. Rename the downloaded ZIP file to 5\_ply\_number\_optimization.zip





# Perform the Optimization with Nastran SOL 200

- 1. A new .zip file has been downloaded
- Right click on the file and click Extract All
- 3. Click Extract on the following window









## Perform the Optimization with Nastran SOL 200

- 1. Inside of the new folder, double click on Start MSC Nastran
- 2. Click Open, Run or Allow Access on any subsequent windows
- 3. MSC Nastran will now start
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
   1) Copy the BDF files and the INCLUDE files to a remote machine.
   2) Run the MSC Nastran job on the remote machine.
   3) After completion, copy the BDF, F06, LOG, H5 files to the local machine.
   4) Click "Start MSC Nastran" to display the results.

### Using Linux?

Follow these instructions:
1) Open Terminal
2) Navigate to the nastran\_working\_directory cd ./nastran\_working\_directory
3) Use this command to start the process ./Start\_MSC\_Nastran.sh

In some instances, execute permission must be granted to the directory. Use this command. This command assumes you are one folder level up.

sudo chmod -R u+x ./nastran\_working\_directory







Questions? Email: christian@ the-engineering-lab.com



### SOL 200 Web App - Status

Status

### Reputhon MSC Nastran

# Status

1. While MSC Nastran is running, a status page will show the current state of MSC Nastran

Name	Status of Job	Design Cycle	RUN TERMINATED DUE TO
model.bdf	Running	None	

 The status of the MSC Nastran job is reported on the Status page. Note that Windows 7 users will experience a delay in the status updates. All other users of Windows 10 and Red Hat Linux will see immediate status updates.



After MSC Nastran is finished, the results will be automatically uploaded.

- Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.
- The final value of objective, normalized constraints (not shown) and design variables can be reviewed.
- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- Note that the optimization solutions is sensitive to different system configurations. This optimization yielded an objective of 2.303103E-05 on Windows 7, but on Linux, yielded an objective of 2.305057E-05. Alternatively, the difference in the converged solution may be due to a difference in the surface area of the ply shape candidates. A difference of one 2D element may yield a different solution.
- Normalized constraint values that are positive indicate a design that violates at least one design constraint, and such designs are named infeasible designs. Negative normalized constraint values are desired and indicated the design satisfies all design constraints. Such designs are named feasible designs. The normalized constraint of the final design is negative, indicating a feasible design.

### SOL 200 Web App - Local Optimization Results

### Final Message in .f06

0 10. RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 0

AND HARD FEASIBLE DISCRETE DESIGN OBTAINED

### Objective

(1









### SOL 200 Web App - Local Optimization Results



Design Cycle

# Review Optimization Results

- 1. Navigate to section Design Variables
- 2. Click Display None
- 3. In the search box, type y
- 4. Click Display All
- Only the ply number variables, e.g. y1, y2,..., are displayed

• All the thickness variables are linked to the ply number variables. On this page, the ply thickness variables are hidden and only the ply number variables are displayed.

Questions? Email: christian@ the-engineering-lab.com



1. Use the mouse to click, hold and drag to create a rectangular zoom box. This will zoom into the selected region.



- 1. Hover the mouse cursor over the points of the final design cycle and the labels will become visible.
- 2. Variable y7, which corresponds to GPLY ID 181000 and 2181000, has a final value of 2.
- 3. Variable y10, which corresponds to GPLY ID 184000 and 2184000, has a final value of 0.3.

The final values are integers and correspond to the number of plies for each ply shape that was created. If the final value is a small fractional values less than 0.5, the ply shape is deemed negligible and is automatically removed from the final BDF files in workspace c.

- For design cycle 10, the ply number variables took on fraction values. For example, ply number variable y5 had a value of approximately .58831 in design cycle 10. When discrete values are desired for a variable, a discrete design cycle is performed, which adjusts the fractional value to an approximate discrete value. For ply number variable y5, the value of .58831 is adjusted to 0.5 in design cycle 10D, where the letter D stands for discrete.
- The optimization yielded a mass of 2.303103E-05, but this was with number variables less than 1.0. After the negligible plies are removed, e.g. v10 (184000 2184000), and the other values are rounded up to 1.0, e.g. 0.8 and 0.7 are rounded to 1.0, the final mass is actually 2.356787E-05.



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Questions? Email: christian@ the-engineering-lab.com

- 1. Open file design\_pcompgs.bdf in a text editor. A comparison will be made.
- 2. A new directory workspace\_c has been created. Open this directory.

😋 🔵 🗢 📗 🕨 caparici 🛛	Downloads > 5_ply_number_optimization >	✓ 49 See	arch 5_pl 🔎
Organize 🔻 Include in	library  Share with  New folder	!≡ ▼	
🔆 Favorites	Name	Date modified	Туре
🧮 Desktop	퉬 арр	4/4/2023 6:58 PM	File folder
🗼 Downloads	퉬 workspace_a	4/4/2023 7:00 PM	File folder
🕮 Recent Places	퉬 workspace_b	4/4/2023 7:00 PM	File folder
	퉬 workspace_c 🛛 🕘	4/4/2023 7:00 PM	File folder
🥞 Libraries	📓 design_model.bdf	4/4/2023 6:58 PM	Notepad++
Documents	design_pcompgs.bdf	4/4/2023 6:58 PM	Notepad++
🌙 Music	📓 model.bdf	4/4/2023 6:59 PM	Notepad++
Pictures	📓 model.f04	4/4/2023 7:00 PM	Notepad++
🛃 Videos	📝 model.f06	4/4/2023 7:00 PM	Notepad++
	🔟 model.h5	4/4/2023 7:00 PM	H5 File
🖳 Computer	📝 model.log	4/4/2023 7:00 PM	Notepad++
🏭 Local Disk (C:)	📝 model.pch	4/4/2023 7:00 PM	Notepad++
🖵 Downloads (\\VBoxS	optimization_results.csv	4/4/2023 7:00 PM	Microsoft Ex
	Start MSC Nastran	4/4/2023 6:58 PM	Shortcut



 Inside of workspace\_c, open file design\_pcompgs.bdf in a text editor.

COO 🗢 📗 « Downloa	ads 5_ply_number_optimization	e_c → ≁	arch wor 🔎
Organize 🔻 Include i	n library 👻 Share with 👻 New folder	!≡ ▼	
🔺 🗙 Favorites	Name	Date modified	Туре
🧮 Desktop	📓 design_model.bdf	4/4/2023 7:00 PM	Notepad++
🗼 Downloads	design_pcompgs.bdf 1	4/4/2023 7:00 PM	Notepad++
🕮 Recent Places	📓 model.bdf	4/4/2023 6:59 PM	Notepad++



Recall the following variable results.

- Variable y7, which corresponds to GPLY ID 181000 and 2181000, has a final value of 2.
- Variable y10, which corresponds to GPLY ID 184000 and 21840000, has a final value of 0.3. Such a small ply number variable suggests the ply shape is negligible.

The following changes have been made in the BDF files found in workspace\_c

- 1. Refer to PCOMPG 3 in both files
- 2. Ply shape 181000 is repeated 2 times as GPLY ID 181001 and 181002.
- 3. Since the composite is symmetric, the same ply shapes are mirrored as 2181001 and 2181002.
- 4. Ply shape 184000 and 21840000 were found to be negligible and have been removed from the final BDF files workspace\_c\design\_pcompgs.bdf.

The BDF files in workspace\_c will be used in a future stacking sequence optimization.

🔚 design_pco	ompgs.bdf 🔀	$\frown$						🔚 design_pco	mpgs.bdf 🔀					
21	PCOMPG	3 (1)			90.	HILL	<b>^</b>	23	PCOMPG	3		0.0	90.	HILL
22		111000	101	.125	90.	YES	_	24		111000	101	.125	90.	YES
23		121000	101	.125	45.	YES	=	25		121000	101	.125	45.	YES
24		131000	101	.125	-45.	YES		26		131000	101	.125	-45.	YES
25		141000	101	.125	0.	YES		27		141000	101	.125	0.0	YES
26		151000	101	1.00000	90.	YES		28		151001	101	.125	90.	YES
27		152000	101	1.00000	90.	YES	8	29		161001	101	.125	45.	YES
28		161000	101	1.00000	45.	YES	8	30		162001	101	.125	45.	YES
29		162000	101	1.00000	45.	YES		31	$\overline{\mathbf{a}}$	171001	101	.125	-45.	YES
30		171000	101	1.00000	-45.	YES		32	2	172001	101	.125	-45.	YES
31	_	172000	101	1.00000	-45.	YES		33		181001	101	.125	0.0	YES
32	、 L	181000	101	1.00000	0.	YES		34		181002	101	.125	0.0	YES
33 4		182000	101	1.00000	0.	YES		35		182001	101	.125	0.0	YES
34		184000	101	1.00000	0.	YES	8	36		191000	501	3.175	0.0	YES
35		191000	501	3.175	0.	YES		37		2191000	501	3.175	0.0	YES
36		2191000	501	3.175	0.	YES		38		2182001	101	.125	0.0	YES
37		2184000	101	1.00000	0.	YES		39		2181002	101	.125	0.0	YES
38	_	2182000	101	1.00000	0.	YES		40	$\bigcirc$	2181001	101	.125	0.0	YES
39		2181000	101	1.00000	0.	YES		41	3	2172001	101	.125	-45.	YES
40		2172000	101	1.00000	-45.	YES		42		2171001	101	.125	-45.	YES
41		2171000	101	1.00000	-45.	YES		43		2162001	101	.125	45.	YES
42		2162000	101	1.00000	45.	YES		44		2161001	101	.125	45.	YES
43		2161000	101	1.00000	45.	YES		45		2151001	101	.125	90.	YES
44		2152000	101	1.00000	90.	YES		46		2141000	101	.125	0.0	YES
45		2151000	101	1.00000	90.	YES		47		2131000	101	.125	-45.	YES
46		2141000	101	.125	0.	YES		48		2121000	101	.125	45.	YES
47		2131000	101	.125	-45.	YES		49		2111000	101	.125	90.	YES
48		2121000	101	.125	45.	YES		50	PCOMPG	4		0.0	90.	HILL
49		2111000	101	.125	90.	YES	8	51		111000	101	.125	90.	YES

### .\5\_ply\_number\_optimization\workspace\_c\design\_pcompgs.bdf



# Part 3 – View New Plies

Questions? Email: christian@ the-engineering-lab.com



# Open the Correct Page

1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5
   Explorer, a web application to extract results from the H5 file type.



# SOL 200 Web App Select a web app to begin Before After Optimization for SOL 200 Multi Model Optimization Machine Learning | Parameter HDF5 Explorer Viewer Study Tutorials and User's Guide Full list of web apps (1)





# Open the Viewer

- 1. Navigate to the Composites section
- 2. Click Viewer

SOL 200 Web App - List of Web Apps

# Beams



PBMSECT

# Composites

Pty	Theta [*]	OPLY ID
1	40	121801
2	-45	121001
3	0	141801
4	30	119201
5	0	147802
6	90	112001
7	9	141003
	45	121802
9	-45	101802

### Stacking Sequence



Questions? Email: christian@ the-engineering-lab.com



# Upload BDF Files

- 1. Click File Upload
- 2. Click Select files
- 3. Navigate to directory workspace\_c
- 4. Select the indicated files
- 5. Click Open
- 6. Click Upload files
- 7. Click Background Color (Optional)



![](_page_99_Picture_10.jpeg)

# Display PCOMPGs

- L. Click Model Display Panel
- Click Iso 3
- 3. Right click and hold the right mouse button, and move the mouse to translate the model into view.
- 4. In the search box, type: pcompg
- 5. Click the indicated icon
- 5. Click the indicated icon
- 7. If an update message appears, wait until the update is complete, then continue
- 8. Click the indicated icon to recolor the plies
- 9. The layer thicknesses is now displayed

![](_page_100_Figure_10.jpeg)

![](_page_100_Picture_12.jpeg)

# Display PCOMPGs

- 1. Click Top
- 2. Click Fit Model
- 3. Use the mouse scroll wheel to zoom in
- 4. The ply thickness varies throughout the composite. The current view is a literal view of the PCOMPG entries.

![](_page_101_Figure_5.jpeg)

![](_page_101_Picture_7.jpeg)

1

# Display GPLYs

- 1. Click the indicated icons
- 2. Click Reset Table
- 3. In the search box, type: gply
- 4. Click the indicated icons
- 5. Click the indicated icon 2 times
- 6. A more realistic view of the plies is displayed
- Alternate between the literal and realistic views to gain a good understanding of how the plies are distributed across the model.

![](_page_102_Figure_8.jpeg)

								(	2 7	Reset Tabl
Property Name	Property ID <sup>⊕</sup>	Color	Display Mesh	Display Wireframe	Layer	GPLY ID	тнета	Color of Detail	Display Detail <sup>©</sup>	Display Detail Wireframe
gply 3	Sear		~	~	s	Sea	Se	5		
			O	OG					OC	OC
GPLY	111000					111000	90°			
GPLY	121000					121000	45°	1)-		<b></b>
GPLY	131000					131000	-45°		<	<
GPLY	141000					141000	0°		<	<
GPLY	151001					151001	90°		<	2
GPLY	161001					161001	45°			
GPLY	162001					162001	45°			
GPLY	163001					163001	45°		<	
GPLY	171001					171001	-45°			
GPLY	172001					172001	-45°		<	
GPLY	173001					173001	-45°			
GPLY	181001					181001	0°			
GPLY	181002					181002	0°			
GPLY	182001					182001	0°			
GPLY	183001					183001	0°			
GPLY	185001					185001	0°		<b>~</b>	<b></b>

![](_page_102_Picture_11.jpeg)

Model Display Panel

# Summary of Optimized Designs

A comparison is made between the starting and final composite designs from phase D. Observe the following:

- 1. ~21% mass savings. The mass of the plies was reduced from 2.229851E-05 to 1.76E-05.
- 2. For the final composite, after stacking sequence optimization, the maximum failure index is .838 and is well under the upper allowed limit of .95.

The ply shape and ply number optimization has been a success.

	Starting Design	Design After Ply Shape and Ply Number Optimization	Design After Stacking Sequence Optimization
	Tutorial Phase B	Tutorial Phase D	Tutorial Phase E
Total Mass	2.825148E-05	2.356787E-05	2.356787E-05
Mass of Non-design Region (Core)	5.952966E-06	5.952966E-06	5.952966E-06
Mass of Design Region (Plies)	2.229851E-05	1.76E-05	1.76E-05
Max Failure Index , Subcase 1	.905 (OK)	.838 (OK)	.838 (OK)
Max Failure Index, Subcase 2	.934 (ОК)	.856 (OK)	.654 (ОК)

![](_page_103_Picture_7.jpeg)

End of Tutorial

![](_page_104_Picture_2.jpeg)

# Appendix

Questions? Email: christian@ the-engineering-lab.com

![](_page_105_Picture_2.jpeg)

# Appendix Contents

- What filter values to use?
- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)
- Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading
- Optimizing Composite Ply Shapes and Numbers for Bending

![](_page_106_Picture_8.jpeg)

# What filter values to use?

Questions? Email: christian@ the-engineering-lab.com

![](_page_107_Picture_2.jpeg)
In this exercise, certain values were used for the threshold. How were these values obtained?

Display Ply Shape	Include in PCOMPGs	GPLY ID	Ply	Candidate	Dependent On Ply	Theta	Action	Threshold Slider	Threshold	Pick Mode	Number of Elements
	2	111000	1	1		90°	+	•	0		2280
	1	121000	2	1		45°	+	•	0		2280
	1	131000	3	1	2	-45°	+	•	0		2280
	1	141000	4	1		0°	+	•	0		2280
	1	151000	5	1		90°	+	•	0		2280
	<	152000	5	2		90°	×		0.47		268
		153000	5	3		90°	×	<b></b>	0.47		268
	1	161000	6	1		45°	+	•	0		2280
	<b>~</b>	162000	6	2		45°	×		0.21		208
	<b>~</b>	163000	6	3		45°	×		0.21		208
	1	171000	7	1	6	-45°	+	•	0		2280
	1	172000	7	2	6	-45°	×		0.21		208
	1	173000	7	3	6	-45°	×		0.21		208
	1	181000	8	1		0°	+	•	0		2280
		182000	8	2		0°	×		0.03		157
	<b>~</b>	183000	8	3		0°	×		0.03		157
		184000	8	4		0°	×		0.02		414
		185000	8	5		0°	×	<b></b>	0.02		414
		191000	9	1		0°	Ð	•	0		2280



Recall that the maximum failure index of the outer 90° plies was originally determined and stored in file model.ply0005. Ply shape candidates were created based on the failure index values.

1. The maximum failure index was found to be 0.934.





- The value 0.934 was divided by 2 (50%) to yield 0.47.
- If more ply shape candidates are desired, additional ply shapes may be constructed with different threshold values, e.g. 10%, 20%, 30% or other percentages.

Display Ply Shape	Include in PCOMPGs	GPLY ID	Ply	Candidate	Dependent On Ply	Theta	Action	Threshold Slider	Threshold	Pick Mode	Number of Elements
	<b>v</b>	111000	1	1		90°	+	•	0		2280
	1	121000	2	1		45°	+	•	0		2280
	<b>v</b>	131000	3	1	2	-45°	+	•	0		2280
	1	141000	4	1		0°	+	•	0		2280
	~	151000	5	1		90°	+	•	0		2280
		152000	5	2		90°	×		0.47		268
		153000	5	3		90°	×		0.47		268





- 1. A similar procedure was done for the +45°, -45° and 0° plies.
- 2. In the case of the 0° plies, whose values are stored in file model.ply0008, the maximum value was found to be .0668. Taking 50% and 25% of the maximum value yields .03 and .02.

	182000	8	2	0°	×	 0.03	157
	183000	8	3	0°	×	 0.03	157
	184000	8	4	0°	×	 0.02	414
<	185000	8	5	0°	×	 0.02	414





# PCOMPG Zones



#### PCOMPG Zones

The ply shapes in the final composite may be controlled. When ply shapes are included or excluded, the PCOMPG zones will vary. Inspect the PCOMPG zones since these zones indicate what the final composite will look like.



# Options for Ply Number Optimization



# Options for Ply Number Optimization





# Options for Ply Number Optimization Constraints on Responses

#### Constraints on Responses

- Ply Stress
- Ply Strain
- Failure Index
- Strength Ratio
- And more

	-1		Sr Strength Ratio
sponse to Show			
Normal-1 Normal-2		*	
Shear-12 Shear-17			
Shear-2Z			
Major principal			
Minor principal Maximum shear			
Failure Index(FP) for dire Failure Index(FB) for inte	ect stresses/strains rlaminar shear-stress		
Strength Ratio(SP) for di Strength Ratio(SB) for in	rect stresses/strains terlaminar shear-stress		



# Options for Ply Number Optimization Constraints on Responses

Response	Stress	Strain
Normal-1	$\sigma_1$	$\mathcal{E}_1$
Normal-2	$\sigma_2$	$\mathcal{E}_2$
Shear-12	$ au_{12}$	γ <sub>12</sub>
Shear-1Z	$ au_{xz}$	$\gamma_{xz}$
Shear-2Z	$ au_{yz}$	$\gamma_{yz}$
Shear Angle	$ heta_p$	$ heta_p$
Major Principal	$\sigma_{max}$	$\varepsilon_{max}$
Minor Principal	$\sigma_{min}$	$\varepsilon_{min}$
Maximum shear	$ au_{max}$	Υmax
Failure Index(FP) for direct stresses/strains	FP	
Failure Index(FB) for interlaminar shear-stress	FB	
Strength Ratio(SP) for direct stresses/strains	SP	
Strength Ratio(SB) for interlaminar shear-stress	SB	



# Options for Ply Number Optimization Responses in F06 File





#### Balance

- **1**. Ensure the starting composite has both  $+\theta$ AND - $\theta$  plies, e.g. ±45°, ±60°, etc.
- 2. Use Link Plies in the web app





(2)

Options

Pick

Mode

Filter

Slider

•

**—** / §

S Link Plies

#### Symmetry

1. Set the laminate option (LAM) to symmetry (SYM)



#### Symmetric



#### Respective PCOMP/PCOMPG Entries

try Name	\$ 1	2	3	4	5	6	п
PCOMPG ~	PCOMPG	2			90.	HILL	
		11100	101	.3755	90.	YES	
minate Ontion		12100	101	.3755	45.	YES	
		13100	101	.3755	-45.	YES	
SYM 1 -		14100	101	.3755	0.	YES	
		15100	501	3.175	0.	YES	
v Number Ontimization		215100	501	3.175	0.	YES	
		214100	101	.3755	0.	YES	
lecklist		213100	101	.3755	-45.	YES	
Ply Thickness		212100	101	.3755	45.	YES	
70 Offect		211100	101	.3755	90.	YES	
J Zu Oliset	PCOMPG	3			90.	HILL	
% Rule Design		11100	101	.3755	90.	YES	
		12100	101	.3755	45.	YES	
Iotal Thickness		12200	101	.3755	45.	YES	
Constraints		13100	101	.3755	-45.	YES	
, oonstanto		13200	101	.3755	-45.	YES	
		14100	101	.3755	0.	YES	
		15100	501	3.175	0.	YES	
A Save New Entries		215100	501	3.175	0.	YES	
		214100	101	.3755	0.	YES	
		213200	101	.3755	-45.	YES	





## Offset to Outer Mold Line

Different manufacturing methods require different offsets.

1. Use Z0 Offset Relationship to ensure the composite is offset to reflect the manufacturing tooling, e.g. outer mold line

#### Offset Default (No Offset)



#### Offset Bottom

Gray Color: Nodal Reference Plane (Tooling/Outer Mold Line)







Additional Optimization Options					
Z0 Offset Relationship	(1)				
Default	C	~			
Default					
Above					
Below					
anonarioso or an layoro.					

Default: -0.5 times the element thickness

- Default: -0.5 times the element thickness
- Above: 1.0 times the element thickness
- Below: -1.0 times the element thickness

% Rule Design					
Theta [θ]	% Lower Allowed Limit	% Upper Allowed Limit			
-45.	Lower	Upper			
0.	Lower	Upper			
45.	Lower	Upper			
90.	Lower	Upper			

Total Thickness	
Lower Allowed Limit	Upper Allowed Limit
Lower	Upper



## 10% Design Rule

During optimization, there may be too few plies of a particular angle, e.g. 90°

1. Use % Rule Design to put a lower bound on the percentage of specific ply angles

# Minimum 20% of plies are 90° No percent constraint Minimum of 10% of plies are 90°

2 plies / 22 plies x 100 = 9%

#### 4 plies / 22 plies x 100 = 18%

% Rule Design					
Theta [θ]	% Lower Allowed Limit	% Upper Allowed Limit			
-45.	Lower	Upper			
	Lower				
0.	Lower	Upper			
45.	Lower	Upper			
90.	10.	1 Upper			
	% Rule Theta [θ] -45. 0. 45. 90.	% Rule DesignTheta [θ]% Lower Allowed Limit-45.Lower0.Lower45.Lower90.10.			

#### 6 plies / 22 plies x 100 = 27%

Upper Allowe	d Limit	
	90.	
	0.	

Upper

hickness r Allowed Limit



## Total Thickness

The optimizer may inadvertently produce a composite that is very thick.

1. Use the Total Thickness option to limit the total thickness of the composite

#### Additional Optimization Options

No Total Thickness Constraint

#### Z0 Offset Relationship

#### Default

Distance from the reference plane to the bottom surface. The element thickness is the total thickness of all layers.

- · Default: -0.5 times the element thickness
- Above: 1.0 times the element thickness
- Below: -1.0 times the element thickness



#### Questions? Email: christian@ the-engineering-lab.com

×



#### With Total Thickness Constraint



# GPLY ID Numbering Convention (sPLC000)



## GPLY ID Numbering Convention (sPLC000)

- When configuring ply shapes, the original PCOMP entry will be replaced by multiple PCOMPG entries. The original PCOMP entry is said to be the parent PCOMP and the new PCOMPG entries are said to be the child PCOMPG entries.
- A ply numbering convention is used by the web app to help identify the origin of the various new plies.

PCOMP

PCOMP 1

#### Child PCOMPGs

PCOMPG 7

Parent PCOMP



90. 8 .3755 90. 101 YES .3755 45. 101 YES 101 .3755 -45. YES .3755 0. 101 YES 501 3.175 0. YES

PCOMPG	2			90.	HILL
	111000	101	1.00000	90.	YES
	121000	101	1.00000	45.	YES
	131000	101	1.00000	-45.	YES
	141000	101	1.00000	0.	YES
	151000	501	3.175	0.	YES
	2151000	501	3.175	0.	YES
	2141000	101	1.00000	0.	YES
	2131000	101	1.00000	-45.	YES
	2121000	101	1.00000	45.	YES
	2111000	101	1.00000	90.	YES
PCOMPG	3			90.	HILL
	111000	101	1.00000	90.	YES
	152000	101	1.00000	90.	YES
	121000	101	1.00000	45.	YES
	162000	101	1.00000	45.	YES
	131000	101	1.00000	-45.	YES
	132000	101	1.00000	-45.	YES

[...]



#### GPLY ID Numbering Convention (sPLC000)

Each ply shape candidate is assigned a GPLY ID formatted in a special numbering convention. This formatted GPLY ID is read from right to left.

- The last 3 digits 000 is a place holder used by the ply number optimization. After ply number optimization, the 3 digits 000 are replaced by 001, 002, 003, etc. and will depend on the number of plies determined by the ply number optimization.
- The next digit C indicates the candidate number of that ply shape. The Viewer web app is used to construct multiple ply shape candidates.
- The digit L indicates the layer in the original parent PCOMP.
- The digit P indicates the ID of the original parent PCOMP entry. If the original ID is long, for example 1008, the ID is reduced to a single digit.
- A leading digit of 2 indicates the ply is a mirror ply and is used when the composite is symmetric.

For example, GPLY ID 141000 indicates the ply shape candidate was constructed based on a parent PCOMP ID=1 AND the ply shape was constructed based on the model.ply0004 file (layer 4 of the parent PCOMP).

#### Parent PCOMP

PCOMP	1			90.	HILL
	101	.3755	90.	YES	Layer 1
	101	.3755	45.	YES	Layer 2
	101	.3755	-45.	YES	Layer 3
	101	.3755	0.	YES	Layer 4
	501	3.175	0.	YES	Layer 5

#### Child PCOMPG

2			90.	HILL
111000	101	1.00000	90.	YES
121000	101	1.00000	45.	YES
131000	101	1.00000	-45.	YES
141000	101	1.00000	0.	YES
151000	501	3.175	0.	YES
2151000	501	3.175	0.	YES
2141000	101	1.00000	0.	YES
2131000	101	1.00000	-45.	YES
2121000	101	1.00000	45.	YES
2111000	101	1.00000	90.	YES
	2 111000 121000 131000 141000 151000 2151000 2141000 2131000 2121000 2111000	2 111000 101 121000 101 131000 101 141000 101 151000 501 2151000 501 2141000 101 2131000 101 2121000 101 2111000 101	2 111000 101 1.00000 121000 101 1.00000 131000 101 1.00000 141000 101 1.00000 151000 501 3.175 2151000 501 3.175 2141000 101 1.00000 2131000 101 1.00000 2121000 101 1.00000	2       90.         111000       101       1.00000       90.         121000       101       1.00000       45.         131000       101       1.00000       -45.         141000       101       1.00000       0.         151000       501       3.175       0.         2141000       101       1.00000       0.         2131000       101       1.00000       -45.         2121000       101       1.00000       45.         2111000       101       1.00000       90.

#### Ply Numbering Convention (sPLC000)

SYM

```
GPLYID=2141000
2 1 4 1 000
Symmetry Flag <| | | | |
PCOMP ID P <---| | | |
LAYER L <-----| |
Candidate C <------| |
ith Ply 000 <------|
```



# Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading



## Axial Loaded Members

- Consider designs A and B subjected to the indicated loading. The maximum allowed axial stress is 90. The material is linear isotropic and homogenous.
- Design A exceeds the allowed axial stress of 90.
- 3. The cross sections are adjusted in design B such that the axial stress is less than 90. Design B satisfies the axial stress limit. For design B, the cross section is expanded by adding strips of area, in thickness increments of 0.1, to the height of the cross section.
  - For a laminated composite with constraints on ply stress, ply strain or failure index, a similar approach may be adopted to minimize the weight while satisfying constraints.



# Composite Analysis Model

- Consider this 120mmx10mm composite strip.
- 2. The ply shapes of the 0° plies will be optimized to minimize weight and satisfy failure index (Hill) constraints. The core is left untouched.

The core is 6.35mm thick and the plies are .125mm thick.



# Composite Analysis Model

- 1. The composite strip is subjected to axial loads.
- 2. The maximum failure index for all plies is mapped along the length of the strip.



## Inspection of Failure Indices

1. It is determined that 10 continuous plies yields a composite that satisfies a maximum failure index of 1.0. The top of the composite has 5 plies and the bottom has 5 plies. Only 5 piles are depicted.

Throughout this example, the maximum failure index of all plies for element i, where i is 11, 12, 13, ..., 289, 290, is plotted along the length of the composite.

Design Model: 20230505 study of ply number optimiz ation/0 original/model.bdf



Technology Partner

# Optimizing One Ply Shape

- 1. Ply 5 is applied only to elements 11, 12, 13, ..., 38, 39, and 40. Ply 5 corresponds to a segment of the failure index plot.
- 2. For elements 61, 62, 63, ...., 289 and 290, only 4 plies are necessary.

Before, 5 plies were needed throughout the composite, but this has been reduced to 4 plies. 5 plies are needed only in the region of high failure index.

• Design Model:

20230505\_study\_of\_ply\_number\_optimiz ation/4\_ply\_number\_optimization/works pace\_c





# Example of a Suboptimal Ply Shape

1. What happens if the ply is too small? Consider ply 5. This ply does not correspond entirely to the failure index plot. The failure index plot now shows the failure index is above 1.0, which is not OK. Ply 5 is insufficient to address the failure index.

• Design Model: 20230505\_study\_of\_ply\_number\_optimiz ation/6\_ply\_number\_optimization/works pace\_c\_b



HEXAGON

Technology Partner

## Example of a Suboptimal Ply Shape, Correction

1. To make up for the insufficient ply 5, a ply number optimization will determine that an additional and fully continuous ply (Ply 6) is necessary. The failure index is now less than 1.0. The composite is now OK.

• Design Model:

20230505\_study\_of\_ply\_number\_optimiz ation/6\_ply\_number\_optimization/works pace\_c\_c\_bad\_ply\_with\_5\_good\_plies



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## Optimal Ply Shapes

1. Plies 2, 3, 4 and 5 correspond to different ply shapes and correspond to the failure index plot. This design is lightweight compared to the composite with 5 continuous plies.

Design Model:

20230505\_study\_of\_ply\_number\_optimiz ation/8\_ply\_number\_optimization/works pace\_c



## Comparison

Before Mass: 4.097700E-06 Max Failure Index: .98 (OK)



#### After Mass: 2.932200E-06 28% mass decrease Max Failure Index: .95 (OK)



1	Legend	
	0	
	0 (Core)	



# Optimizing Composite Ply Shapes and Numbers for Bending



# Composite Analysis Model

- L. Consider this 100mmx10mm composite strip.
- 2. The ply shapes of the 0° plies will be optimized to minimize weight and satisfy failure index (Hill) constraints.

The plies are .125mm thick. A total of 40 plies are initially used to satisfy failure index constraints.



## Composite Analysis Model

- 1. The composite strip is subjected to 4 moments.
- The maximum failure index occurs at the outer plies. The maximum failure index of plies 1 and 40 are plotted along the length of the strip.

#### Acknowledgement

Some observers will realize that the maximum displacement of this model is 30mm, which exceeds the assumption of small deformations, and the moments applied are very large. This is acknowledged and done on purpose to yield maximum failure indices on the range of 0 to 1.0. The goal of this exercise is to demonstrate the procedure and focus on failure indices.





## Inspection of Failure Indices

1. It is determined that 40 continuous plies yields a composite that satisfies a maximum failure index of 1.0. The top of the composite has 20 plies and the bottom has 20 plies. Only 20 piles are depicted.

Design Model: 20230506\_study\_of\_ply\_number\_optimization\_ bending\2\_starting





## Optimal Ply Shapes

- 1. Various ply shapes are constructed that correspond to the different steps of the failure index plot. This yields a optimal composite.
- Notice the failure index is closer to 1.0 throughout the composite and indicates material is being efficiently used.
- 3. For elements 211, 212, ..., 239, 240, the number of plies needed is 2 and the failure index is close to 0. This region is a candidate for removing part of the structure, i.e. introduce a hole or cutout.

Design Model:

20230506\_study\_of\_ply\_number\_optimization\_ bending\6\_ply\_number\_optimization\workspace \_c





#### Comparison

#### 1. Mass, Before: 9.990000E-06

2. Mass, After: 5.685975E-06

43% decrease Max failure index = 9.5323E-01 < 1.0 (OK)



# Comparison

- 1. Mass, Before: 9.990000E-06
- 2. Mass, After: 5.685975E-06

43% decrease Max failure index = 9.5323E-01 < 1.0 (OK)


## Consideration of PCOMP

- The SOL 200 Web App supports composite optimization. If bending is a primary focus, the composite configuration C should be used during the optimization process.
  Configuration C involves a fixed layer 1 and 4. Layer 2 and 3 is allowed to vary during the ply shape and ply number optimization.
  - Why? Consider configuration B, which has 2 layers. The failure index is computed at the midplane of each layer, but the failure index towards the outer fibers may be significantly higher. For configuration A, the failure index of layer 1 is approximately 1.0, but configuration B is reporting a failure index of ~0.2. Configuration C reports a failure index of ~1.0 for ply 1.

It should be noted that the composite thickness of each configuration is an equal value of 5 mm (40 plies with each ply has a thickness of .125mm). The LAM=SYM option indicates the layers listed on the PCOMP are doubled to create a symmetric composite.



## Consideration of PCOMP

1. If other angles, such as 90 or 45 degrees, are considered, fix a few plies on the top and bottom of the composite.

For the example shown, angle 0, 45, -45 and 90 are used. The top has 4 fixed plies (thickness of .125mm), followed by 4 layers with thickness .5mm. The 4 layers with .5mm will vary during the optimization. The plies with .125mm will remain as is during the ply shape and ply number optimization.



PCOMP	2			9
	101	.125	90.	Y
	101	.125	45.	Y
	101	.125	-45.	
	101	.125	0.	Y
	101	.5	90.	Y
	101	.5	45.	Y
	101	.5	-45.	
	101	.5	0.	Y



Y----- X Z



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