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

AN MSC NASTRAN SOL 200 TUTORIAL

Composite Workshop

This workshop is phase B 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

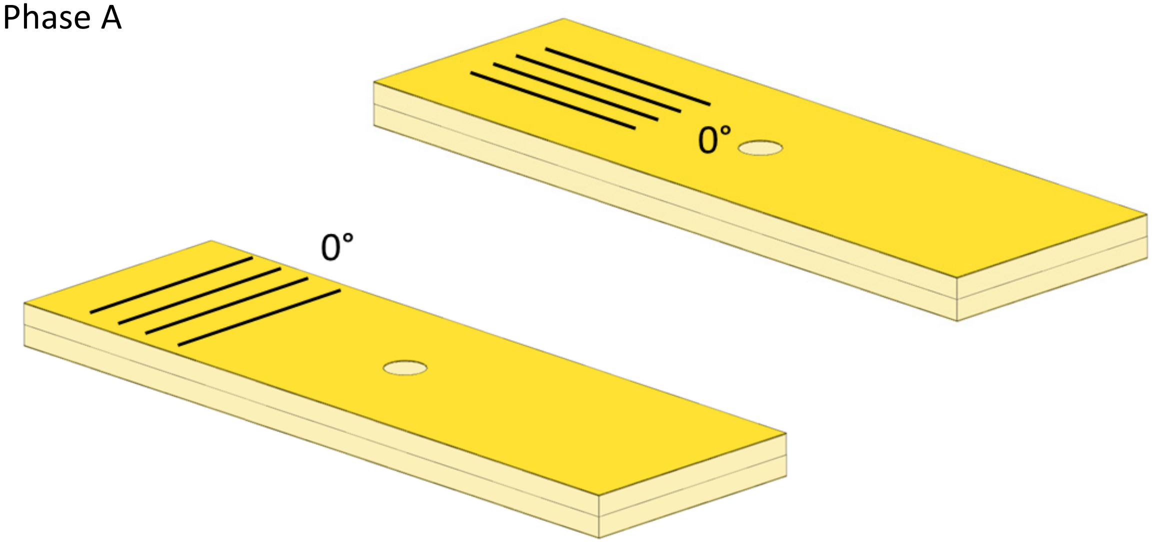
- Perform a ply number optimization with full and continuous ply shapes
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

0° Direction Optimization → Baseline Ply Number Optimization

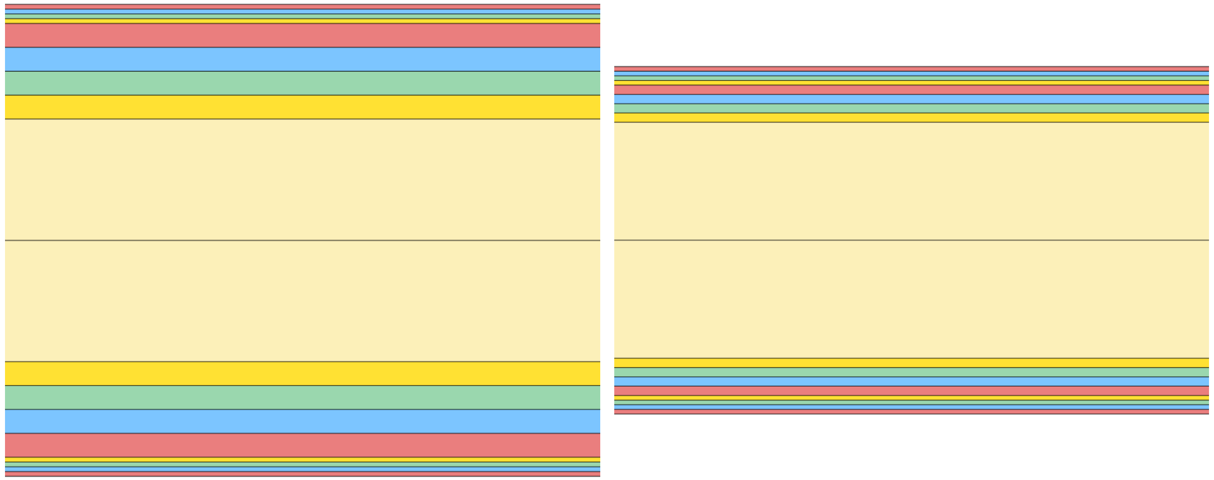
Composite Workshop

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

Phase A



Phase B



0° Direction Optimization → Baseline Ply Number Optimization

Composite Workshop

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

Phase C

Workshop – Composite Coupon – Phase C – Data Preparation for Ply Shape Optimization

- Manually create PLY000i Files

- Tools Used: Patran, MSC Nastran and SOL 200 Web App

Phase D

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

- Input BDF and PLY000i Files
- Create Ply Shapes
- Perform Ply Number Optimization
- Inspect Plies

- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

Phase E

Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization

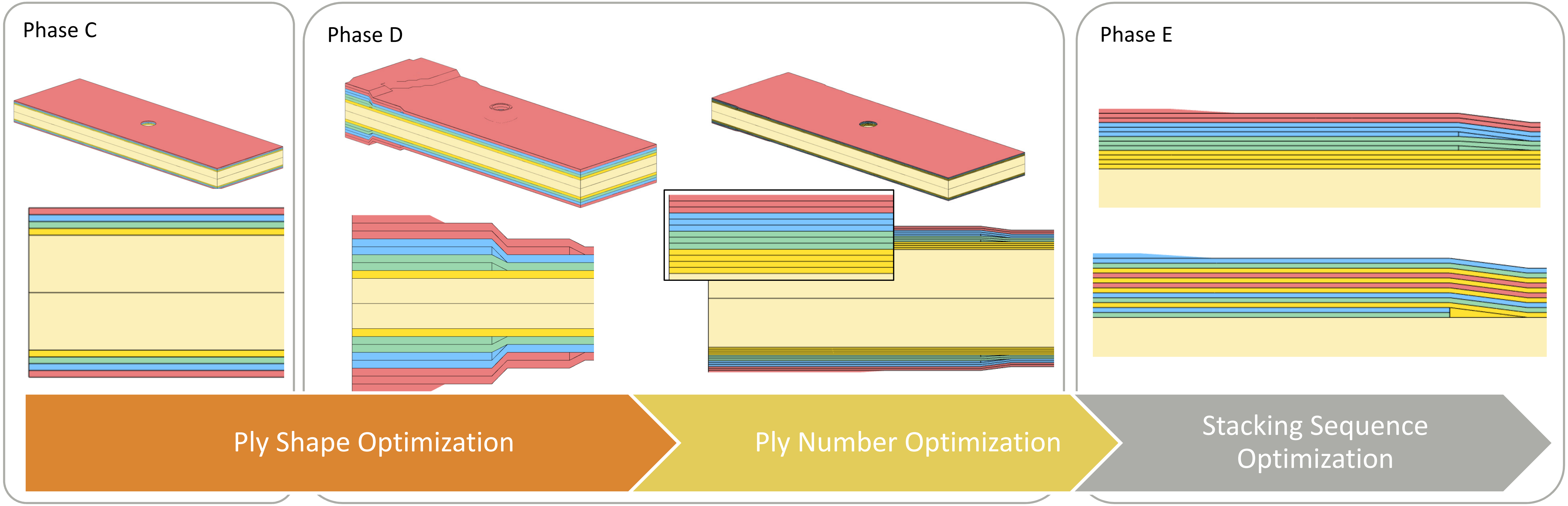
- Input BDF
- Perform Stacking Sequence Optimization
- Validate Performance
- Inspect Plies

- Tools Used: SOL 200 Web App (Stacking Sequence and Viewer web apps) and MSC Nastran

Ply Shape Optimization → Ply Number Optimization → Stacking Sequence Optimization

Composite Workshop

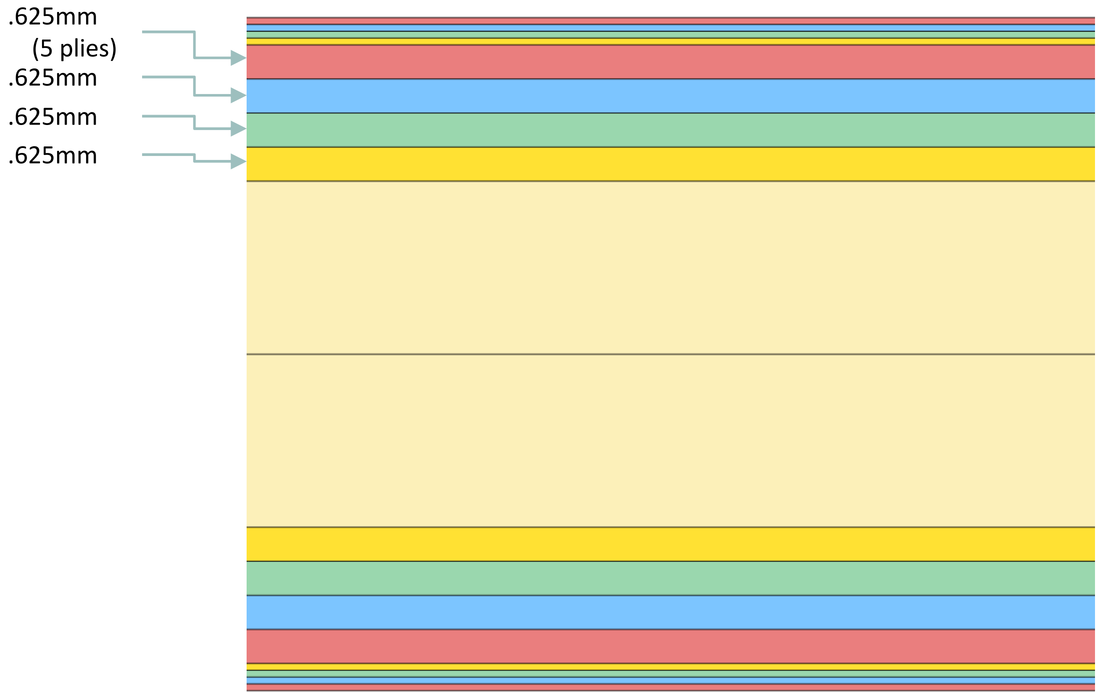
This workshop is phase B of a 5-phase workshop.



Goal: Use Nastran SOL 200 Optimization

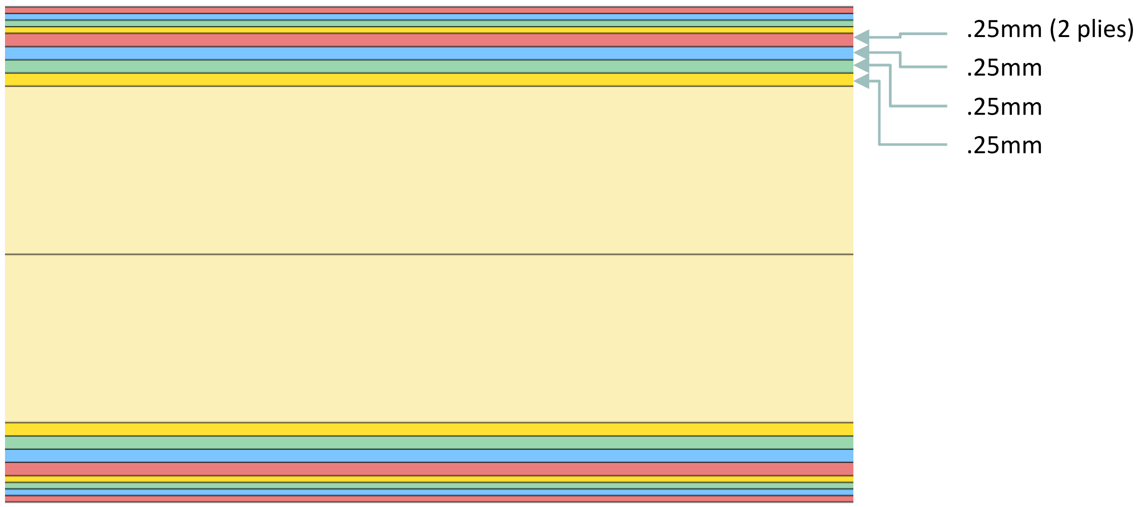
Before Optimization

- Weight: 5.054999E-05
- Max Failure Index of Outer Plies: .235

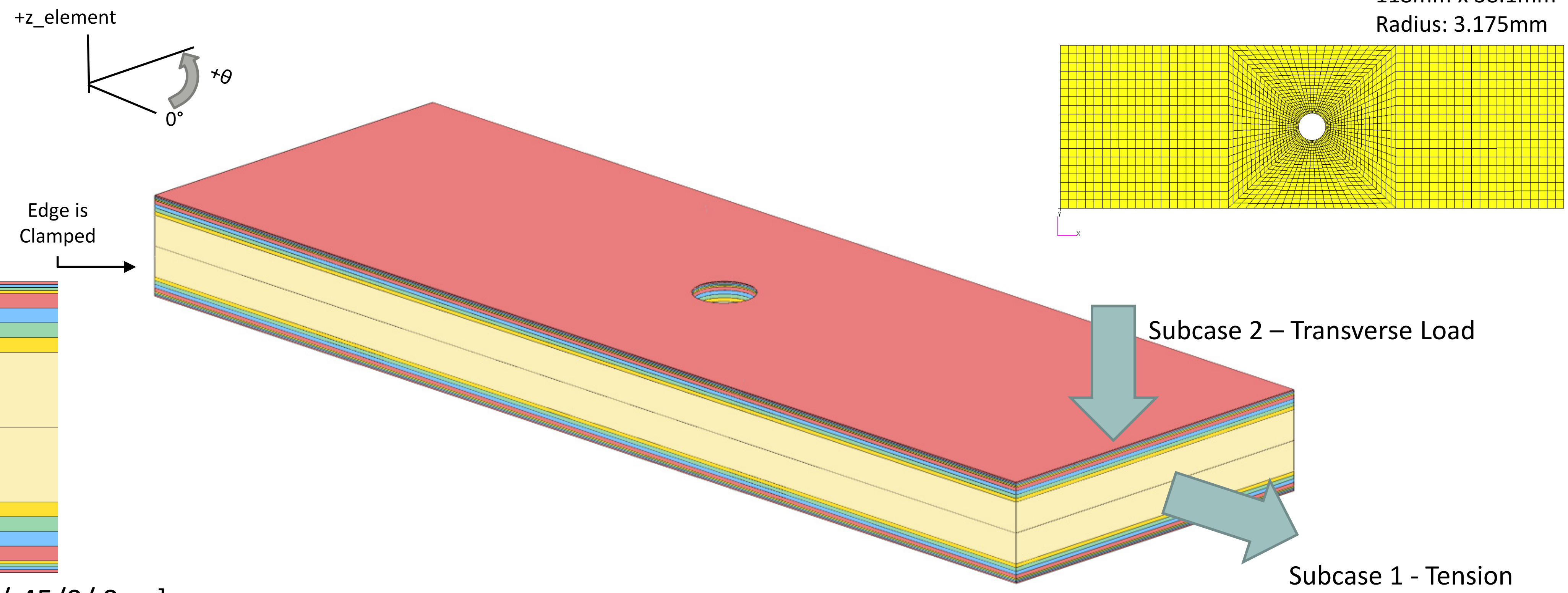


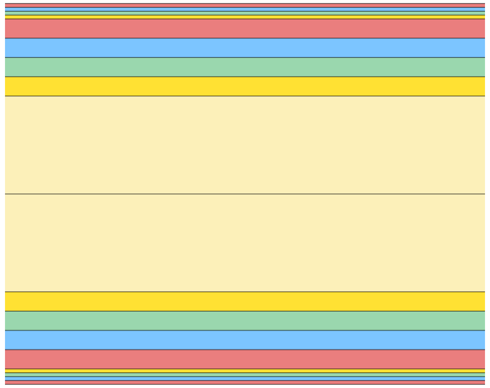
After Optimization

- Weight: 2.825148E-05
- Max Failure Index of Outer Plies: .934



Details of the structural model





[90/+45/-45/0/90/+45/-45/0/ $0_{core}]_s$

118mm x 38.1mm
Radius: 3.175mm

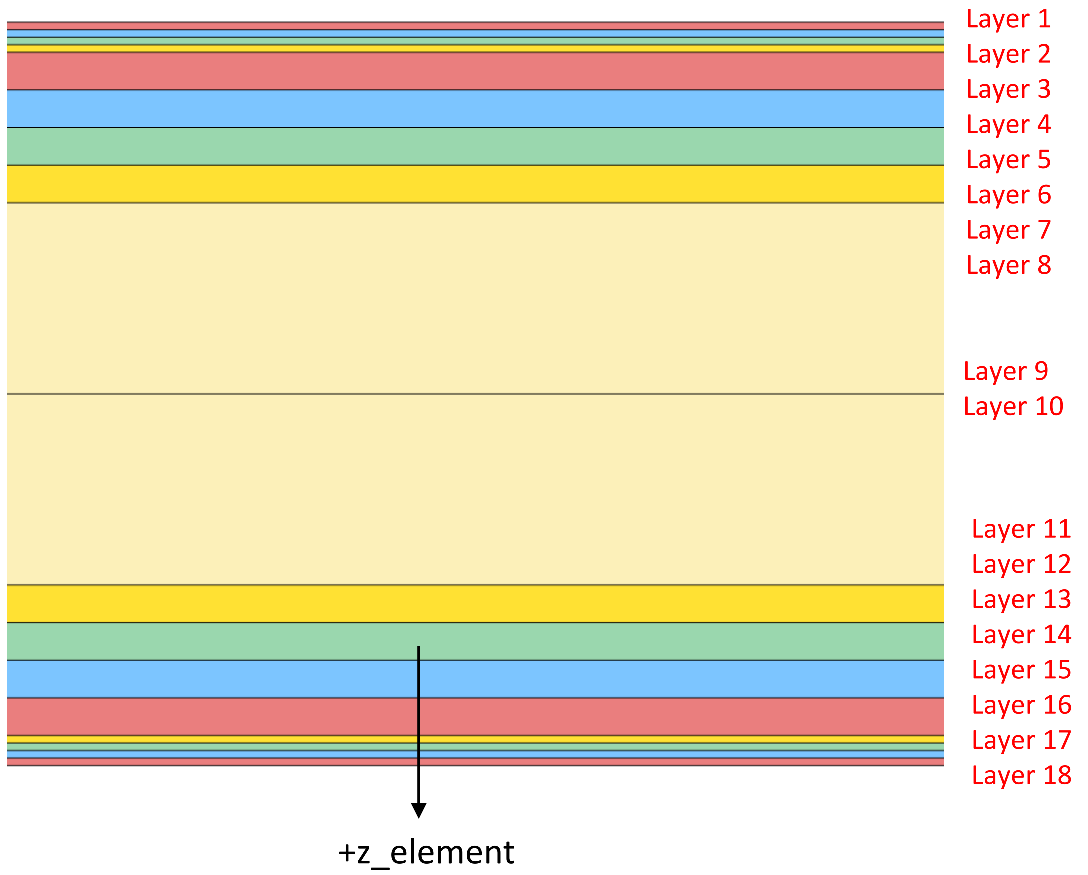
Details of the Composite Layers

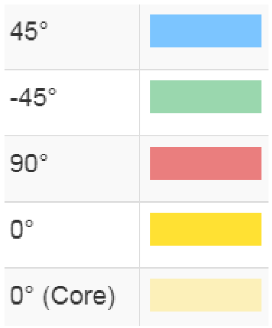
This composite consists of 18 layers.

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.

- Core Layers - Layers 9 and 10 correspond to the core.
- Ply Layers - 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.
- Super-ply 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.

- What is a ply layer, super-ply layer and core layer? See the appendix, section *What is a layer on the PCOMP entry?*






```
PCOMP   1                       90.     HILL                    SYM
        101     .125    90.     YES Layer 1
        101     .125    45.     YES Layer 2
        101     .125    -45.    YES Layer 3
        101     .125    0.      YES Layer 4
        101     .625    90.     YES Layer 5
        101     .625    45.     YES Layer 6
        101     .625    -45.    YES Layer 7
        101     .625    0.      YES Layer 8
        501     3.175   0.      YES Layer 9
```

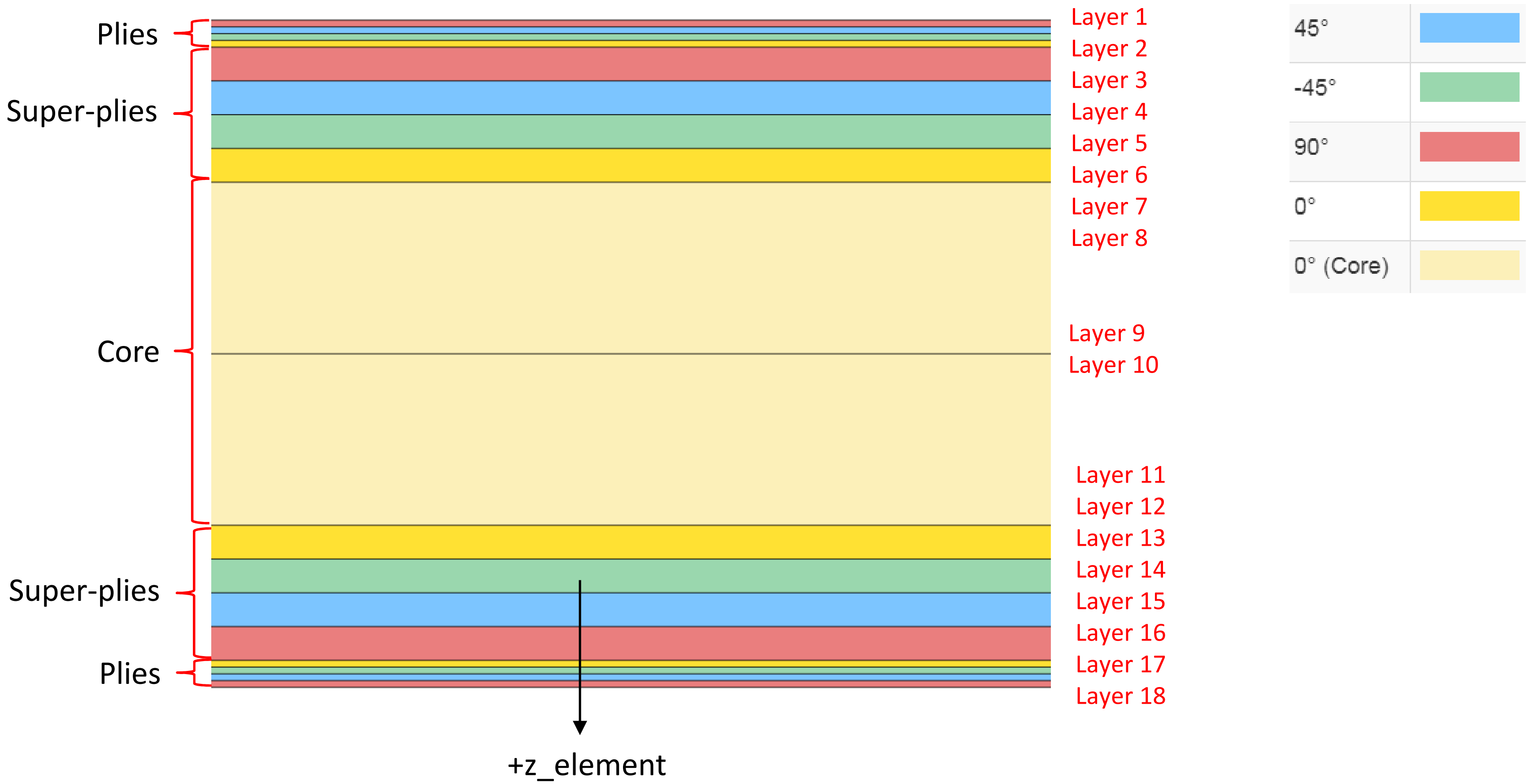
PCOMP Format for Optimization

When optimizing the layer thicknesses of a PCOMP entry, the format of the PCOMP entry needs special consideration. For more information, refer to the appendix, section *PCOMP Format for Optimization*.

1. Since the failure index of the plies will be constrained, the outer most layers are ply layers. The failure indices of only the outermost ply layers are constrained. The thickness of the ply layers is fixed during the optimization. The thickness of the super-ply layer varies during the optimization.

2. The 0° super-ply layers are purposely placed towards the midplane and the 90° super-ply layers are placed furthest from the midplane

For more information, refer to the appendix, section *PCOMP Format for Optimization*.




```
PCOMP,1,,,90.,,,,SYM
          101      .125     90.       YES Layer 1
          101      .125     45.       YES Layer 2
          101      .125    -45.       YES Layer 3
          101      .125      0.       YES Layer 4
          101      .625     90.       YES Layer 5
          101      .625     45.       YES Layer 6
          101      .625    -45.       YES Layer 7
          101      .625     0.        YES Layer 8
          501      3.175    0.        YES Layer 9
```

Optimization Problem Statement

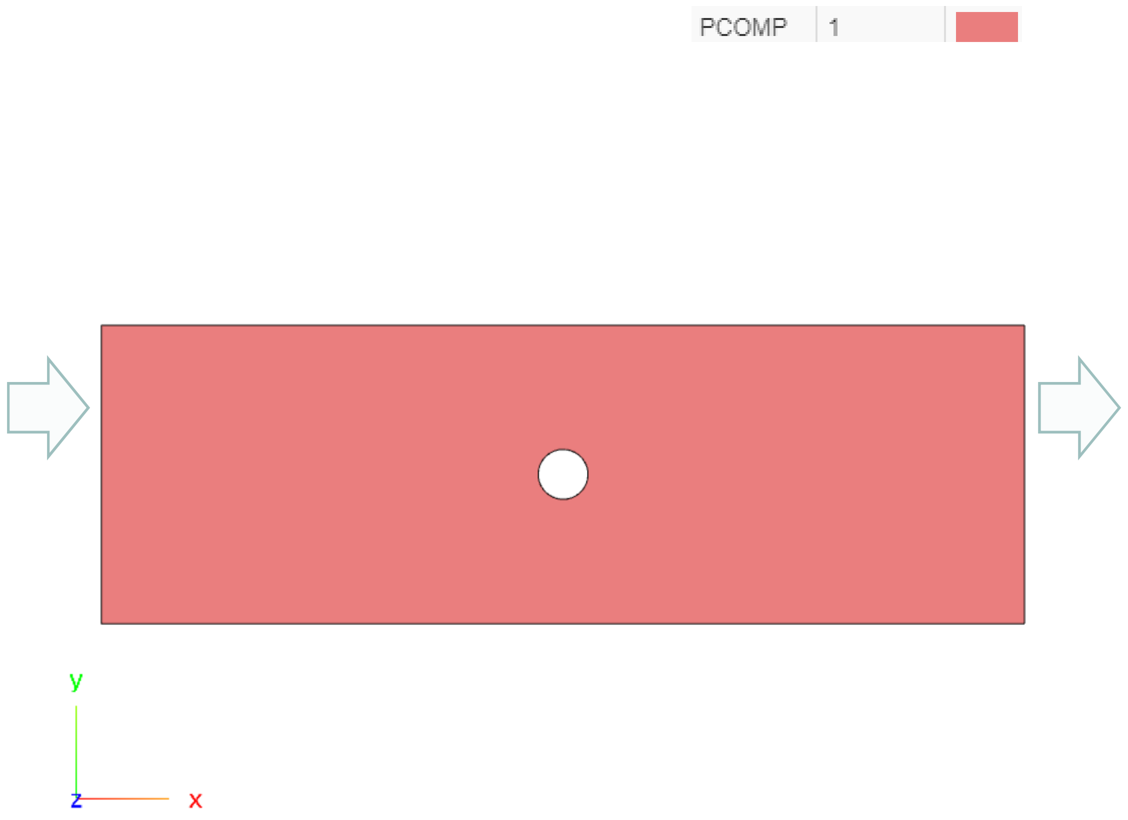
Design Variables

x1: T5, Thickness of layer 5 (90°), of PCOMP 1 (pcomp.1)
x2: T6, Thickness of layer 6 (45°), of PCOMP 1 (pcomp.1)
x3: T7, Thickness of layer 7 (-45°), of PCOMP 1 (pcomp.1)
x4: T8, Thickness of layer 8 (0°), of PCOMP 1 (pcomp.1)

y1: Number of plies

- Initial value: 1.0
- Lower Bound: 1.0
- Upper Bound: 200.0
- Allowed Discrete Values: 1, 2, 3, …, 199, 200

Variable Links
x1 = y1 * .125
x2 = y1 * .125
x3 = y1 * .125
x4 = y1 * .125



Design Objective

Minimize r0: weight

Design Constraints

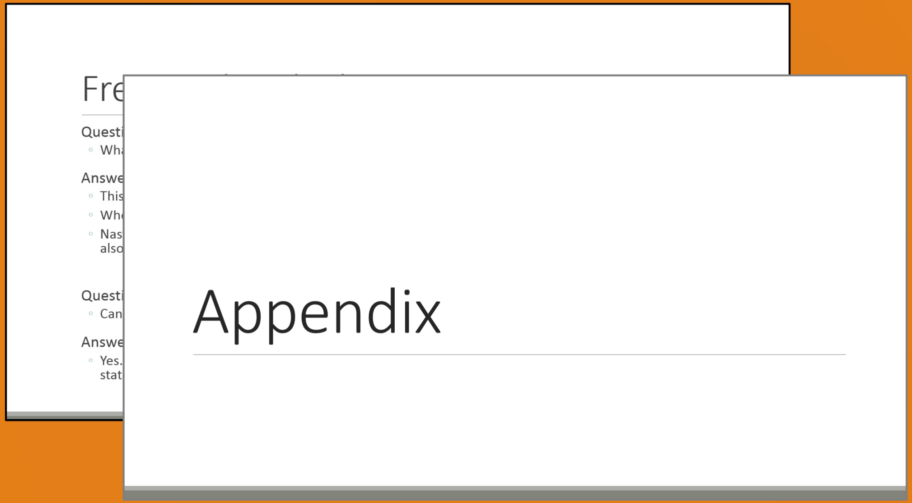
ri: Failure index of outer plies 1, 2, 3, 4, 15, 16, 17, 18

ri < .95

More Information Available in the Appendix

The Appendix includes information regarding the following:

- What is a layer on the PCOMP entry?
- PCOMP Format for Optimization
  - Comments on Ply Output
  - Consideration of Initial Stacking Sequence When Performing Composite Ply Shape And Ply Number Optimization Under Bending Loads
- Why is the ply number optimization configured to start with 1 ply instead of the original 5 plies?



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. Start with a .bdf or .dat file
2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Variables
     - Design Objective
     - Design Constraints
   - Perform optimization with Nastran SOL 200
3. Plot the Optimization Results
4. Update the original model with optimized parameters

Special Topics Covered

Ply Number Optimization - Ply thickness optimization is straightforward, but ply number optimization requires an extra step when defining variables. This tutorial demonstrates the process to configure ply number variables.

SOL 200 Web App Capabilities

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

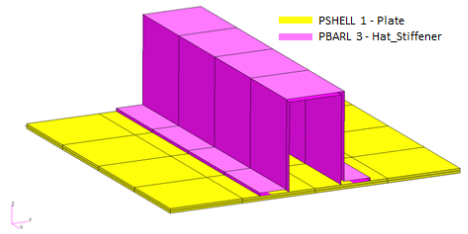
Compatibility

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

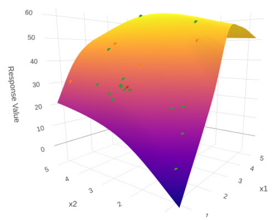
Benefits

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

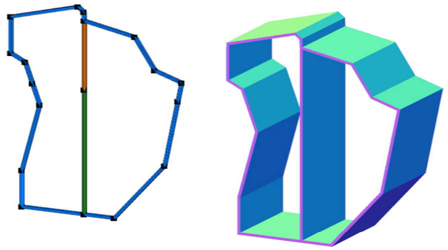
Web Apps



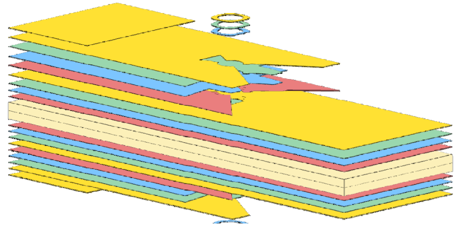
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



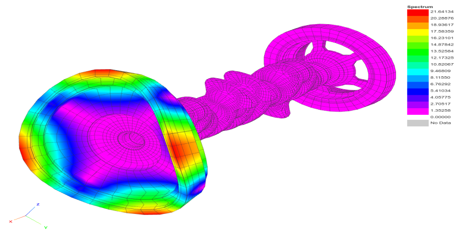
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



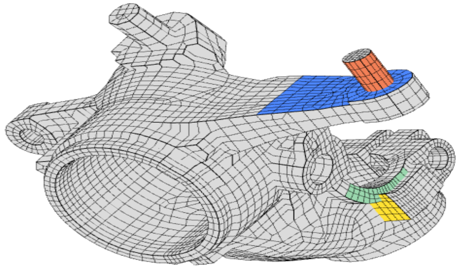
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



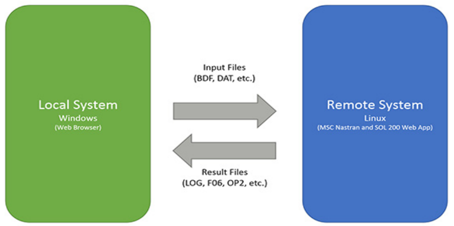
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



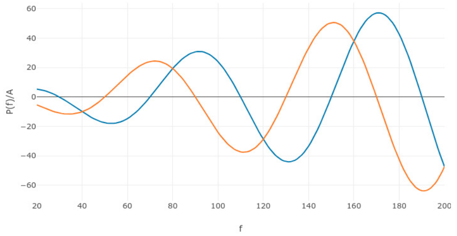
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



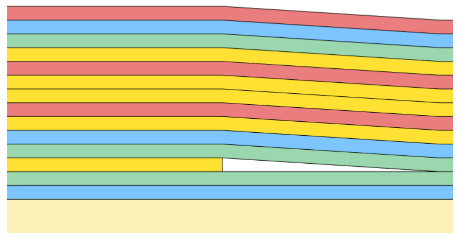
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



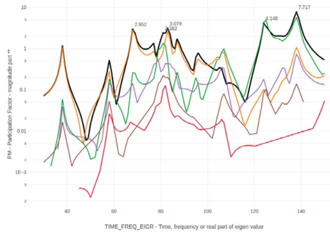
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



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

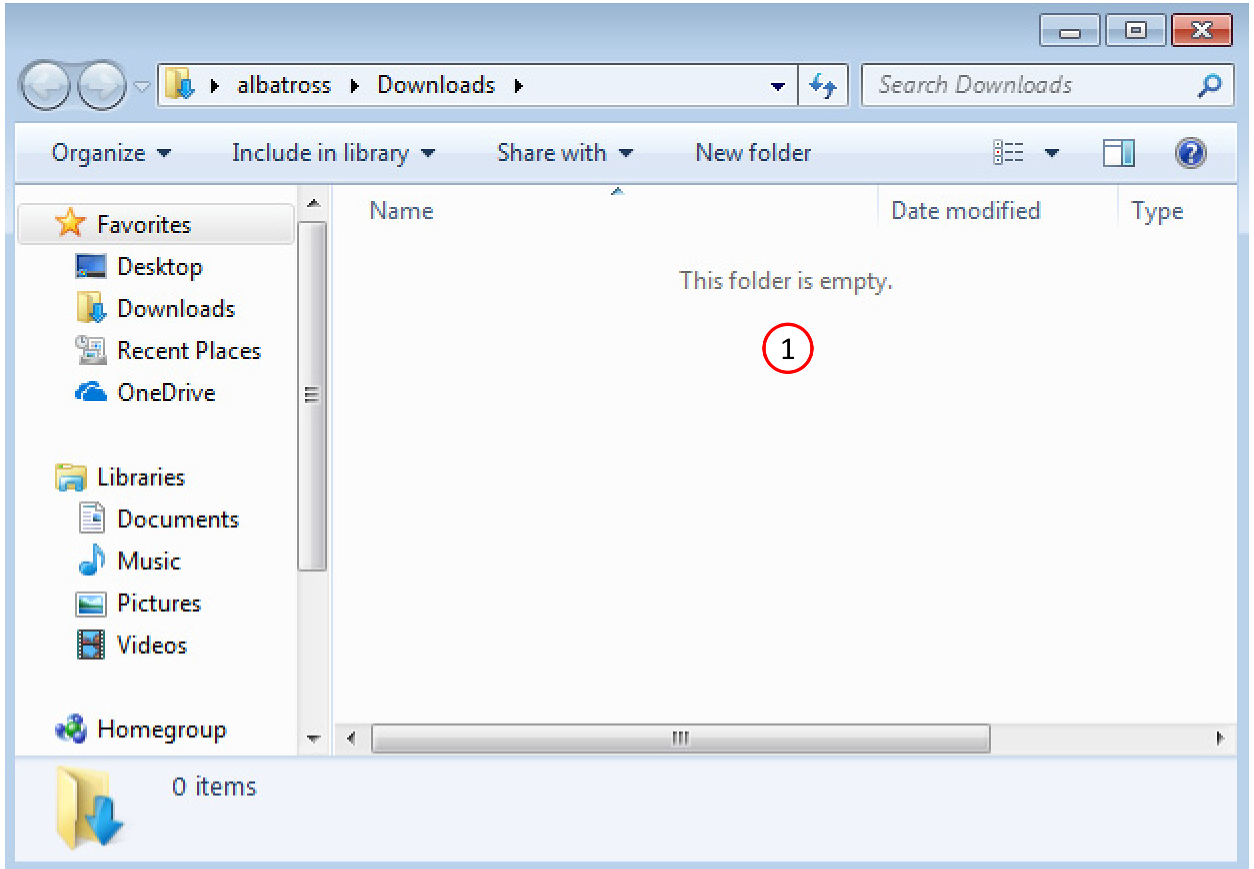


HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

Before Starting

1. Ensure the Downloads directory is empty in order to prevent confusion with other files

- 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.



Go to the User's Guide

1. Click on the indicated link

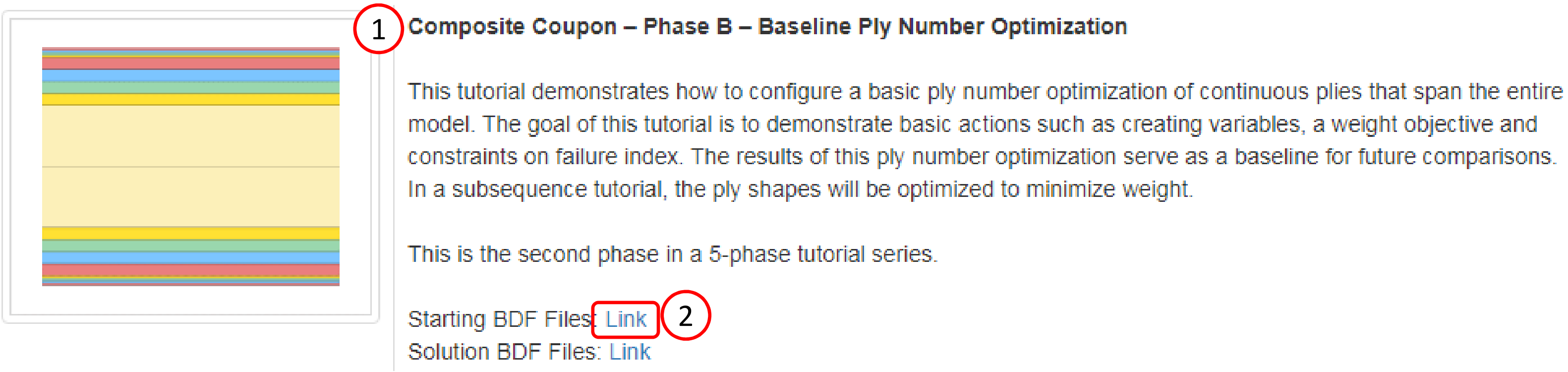
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

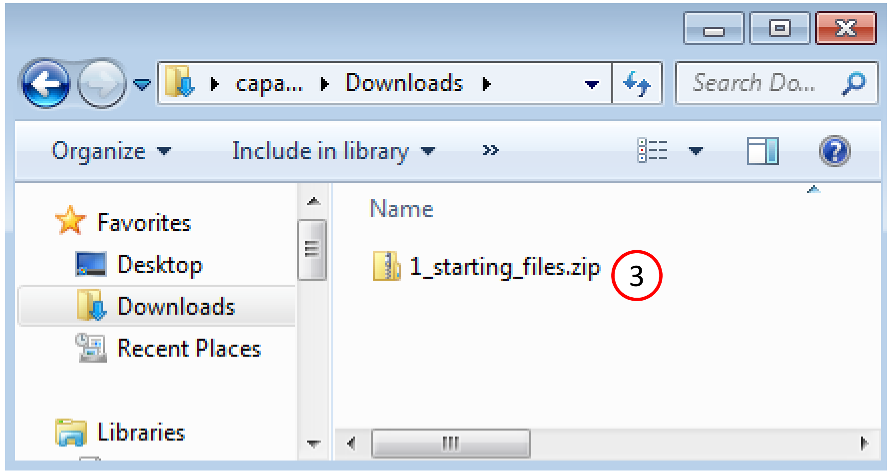
The Engineering Lab

Obtain Starting Files

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

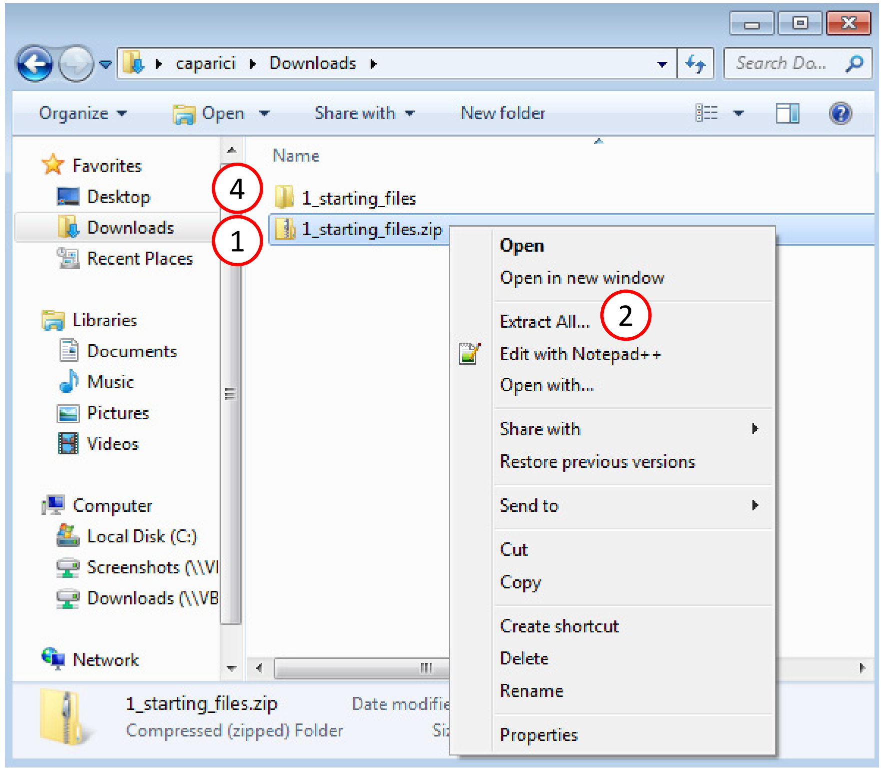
- When starting the procedure, all the necessary BDF files must be collected together.

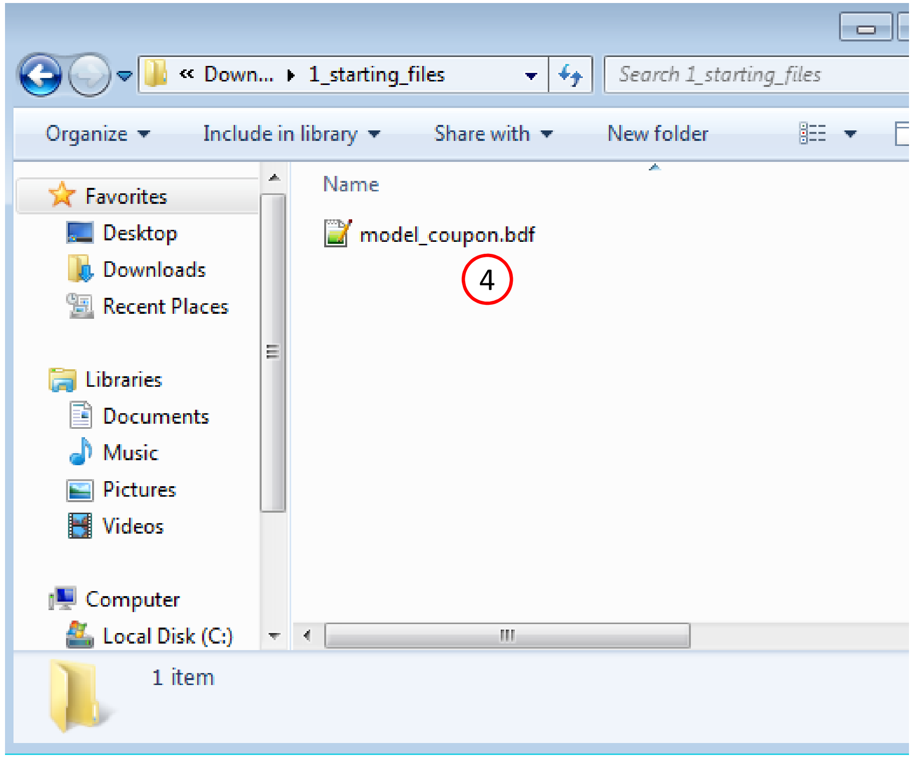


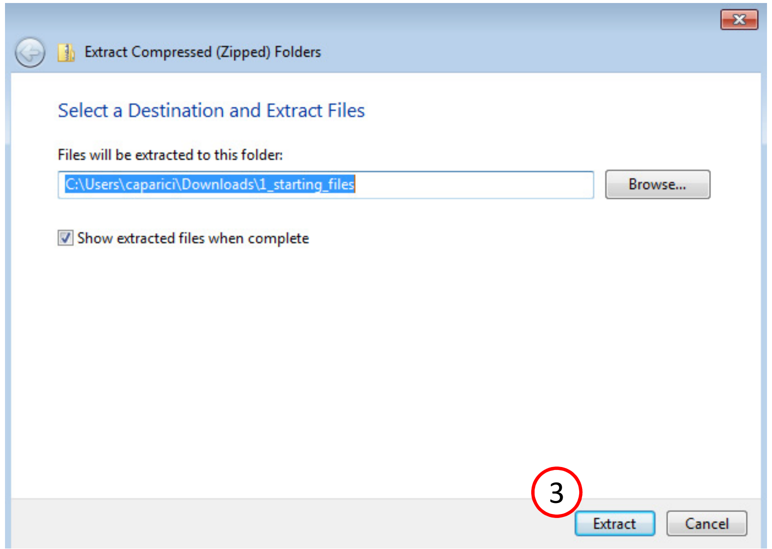


Obtain Starting Files

1. Right click on the zip file
2. Select Extract All…
3. Click Extract
4. The starting files are now available in a folder







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

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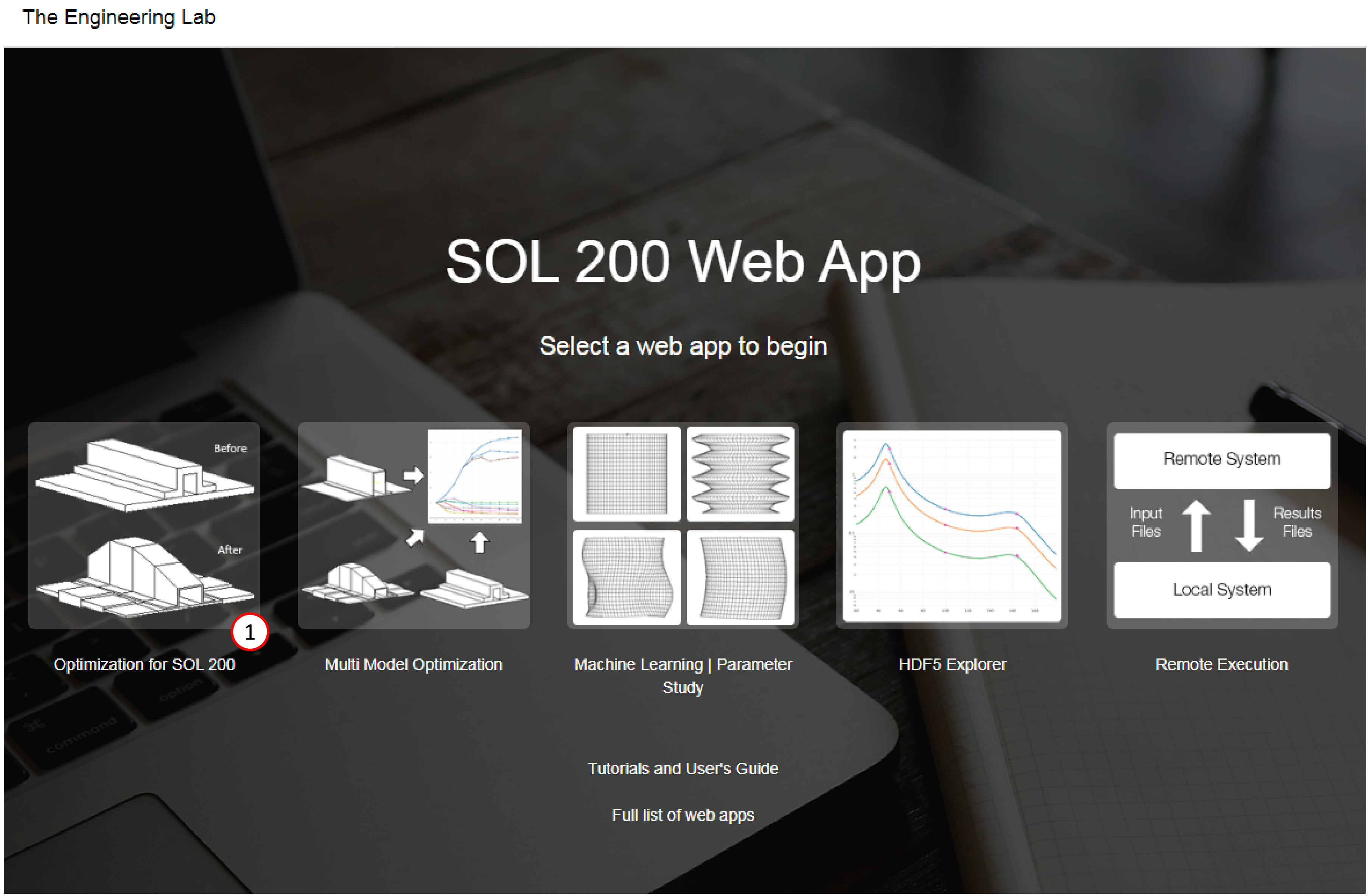
Open the Correct Page

1. Click on the indicated link

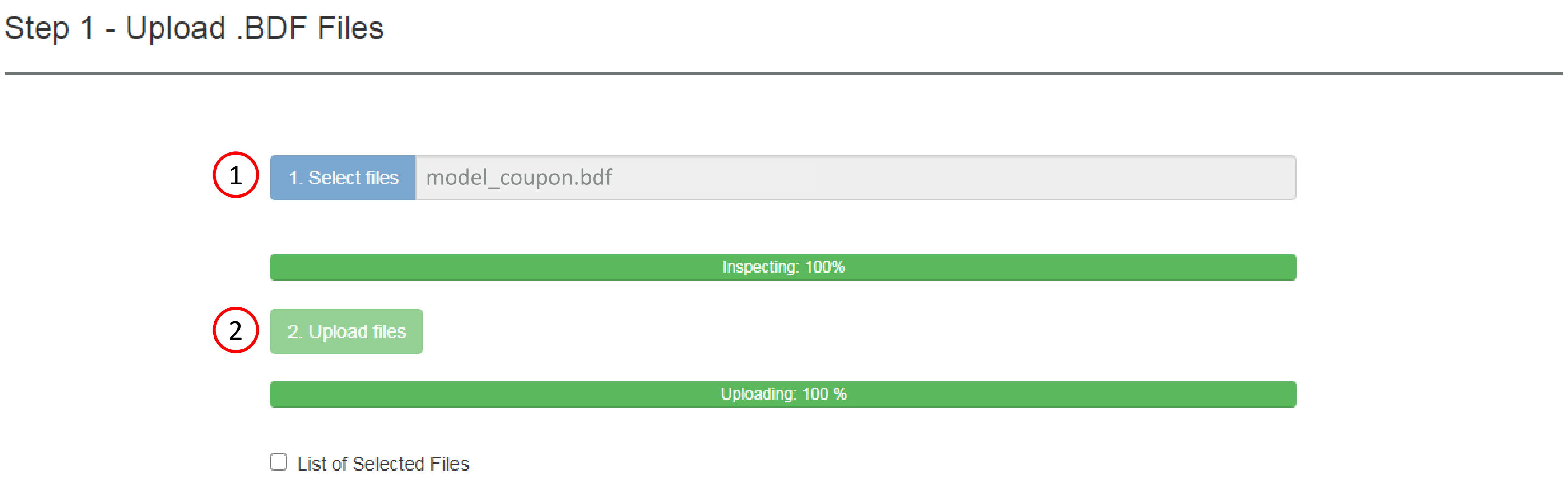
- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
    - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
    - Multi Model Optimization
    - Machine Learning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



Upload BDF Files

1. Click 1. Select Files and select model_coupon.bdf
2. Click Upload Files

- The process starts by uploading all the necessary BDF files. The BDF files can be files of your own or files found in the Tutorials section of the User’s Guide.



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Create Design Variables

1. In the search box, type: thickness
2. Click 10 on the pagination bar to display at most 10 rows in the table
3. Click on the plus (+) icons to set the 4 layer thicknesses as design variables
4. Confirm 4 design variables have been created

- Each step has hidden functionality for advanced users. The visibility is controlled by clicking + Options.
- If the property entry, e.g. PSHELL, was given a name in Patran, e.g. Car Door, the name can be shown by marking the checkbox titled Entry Name.

Step 1 - Select design properties

+ Options

Create DVXREL1	Property	Property Description	Entry	Entry ID	Current Value
	Search	thickness (1)	Search	Search	Search
+	T1	Thickness of layer 1 (90°)	PCOMP	1	.125
+	T2	Thickness of layer 2 (45°)	PCOMP	1	.125
+	T3	Thickness of layer 3 (-45°)	PCOMP	1	.125
+	T4	Thickness of layer 4 (0°)	PCOMP	1	.125
+ (3)	T5	Thickness of layer 5 (90°)	PCOMP	1	.625
+ (3)	T6	Thickness of layer 6 (45°)	PCOMP	1	.625
+ (3)	T7	Thickness of layer 7 (-45°)	PCOMP	1	.625
+ (3)	T8	Thickness of layer 8 (0°)	PCOMP	1	.625
+	T9	Thickness of layer 9 (0°)	PCOMP	1	3.175

5 | 10 | 20 | 30 | 40 | 50 (2)

Number of Visible Rows 10

Step 2 - Adjust design variables

✖ Delete Visible Rows

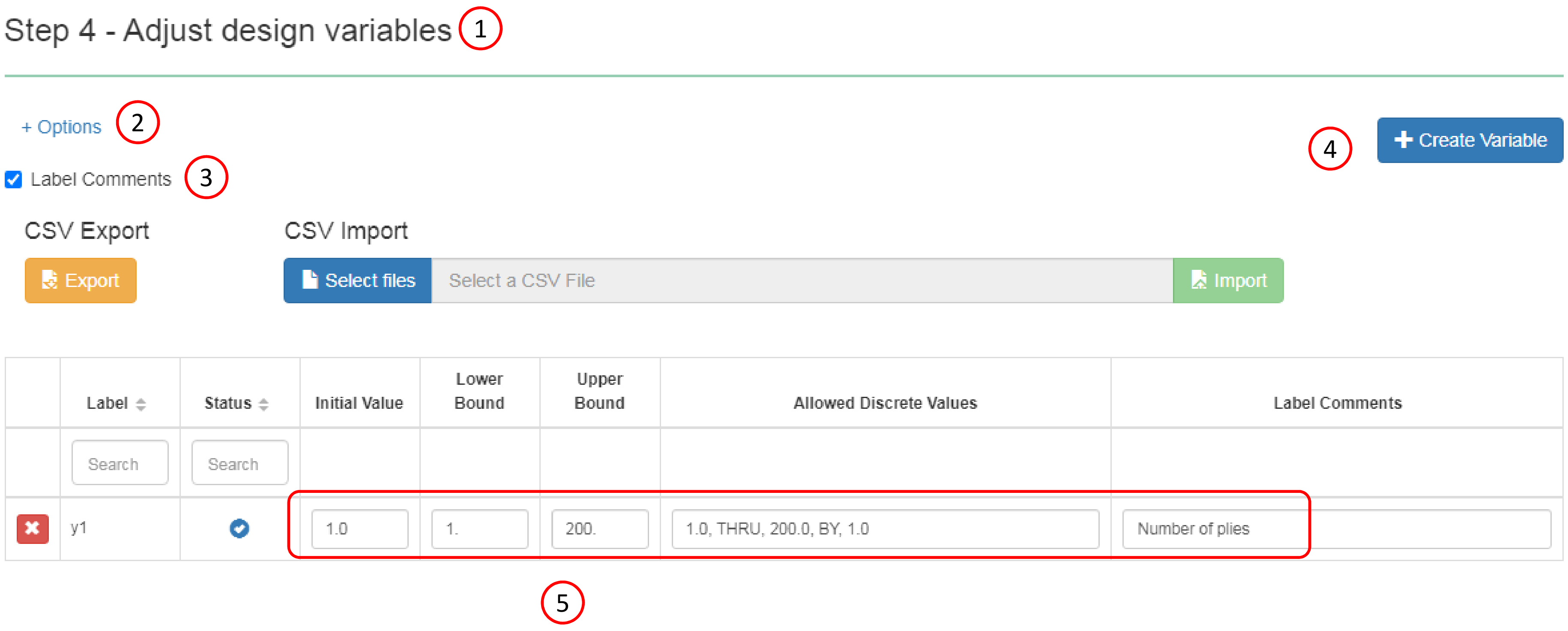
+ Options

	Label	Status	Property	Property Description	Entry	Entry ID	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	Search	Search	Search
✖	x1	✔	T5	Thickness of layer 5 (90°)	PCOMP	1	.625	.001	Upper	Examples: -2.0, 1.0, THRU, 10.0,
✖	x2 (4)	✔	T6	Thickness of layer 6 (45°)	PCOMP	1	.625	.001	Upper	Examples: -2.0, 1.0, THRU, 10.0,
✖	x3	✔	T7	Thickness of layer 7 (-45°)	PCOMP	1	.625	.001	Upper	Examples: -2.0, 1.0, THRU, 10.0,
✖	x4	✔	T8	Thickness of layer 8 (0°)	PCOMP	1	.625	.001	Upper	Examples: -2.0, 1.0, THRU, 10.0,

Create Design Variables

1. Scroll to section Step 4 – Adjust design variables
2. Click +Options
3. Mark the checkbox for Label Comments
4. Click Create Variable
5. A new variable y1 is created. Configure the following settings.
   - Initial Value: 1.0
   - Lower Bound: 1.0
   - Upper Bound: 200.0
   - Allowed Discrete Values: 1.0, THRU, 200.0, BY, 1.0
   - Label Comments: Number of plies

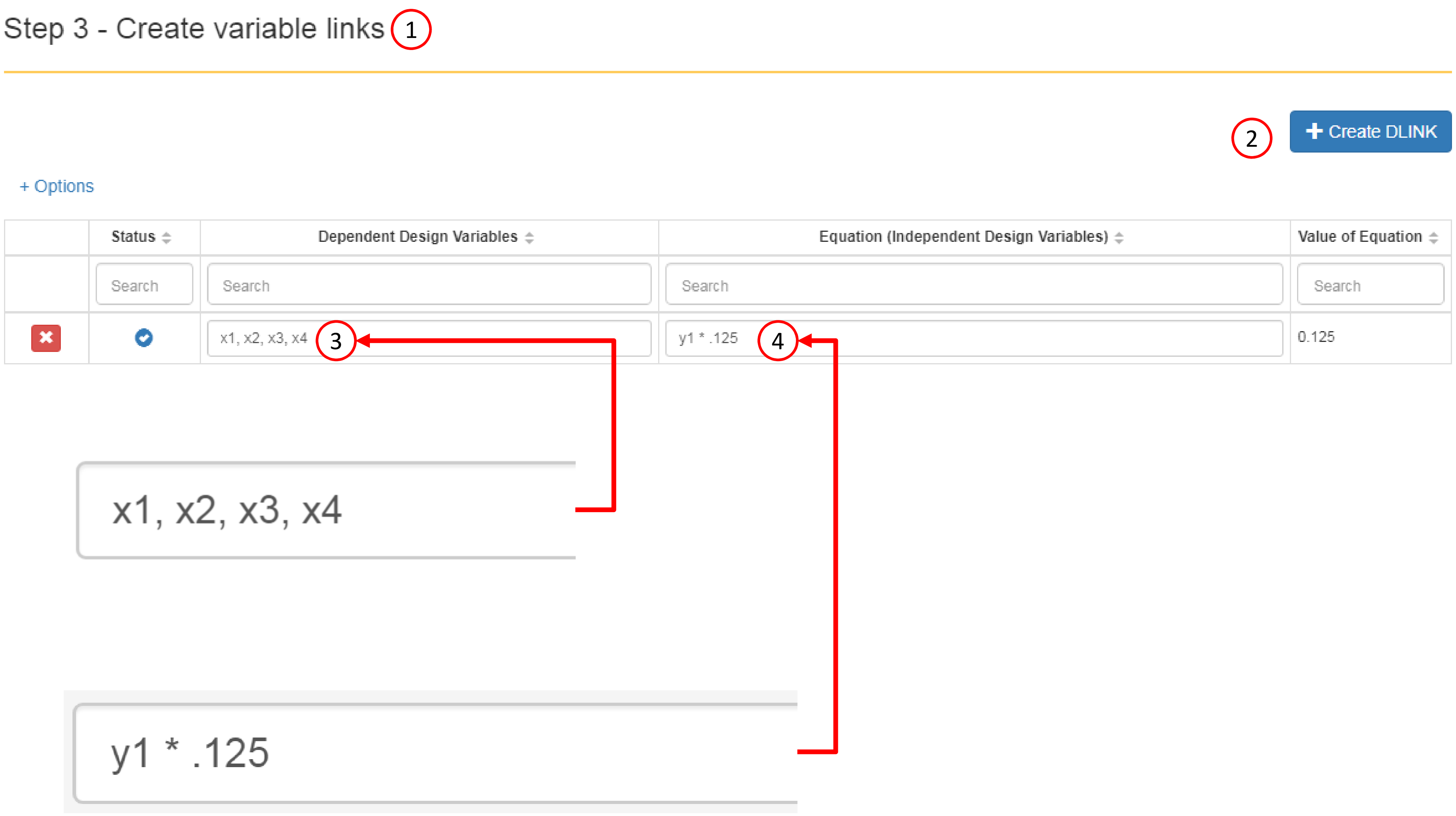
The initial number of plies is set to 1. Why is the ply number optimization configured to start with 1 ply (.125) instead of the original 5 plies (.625/.125=5)? Refer to the appendix, section *Why is the ply number optimization configured to start with 1 ply instead of the original 5 plies?*



Create Design Variables

1. Navigate to section Step 3 – Create variable links
2. Click Create DLINK
3. Set the Dependent Design Variable as x1, x2, x3, x4
4. Set the Equation as y1 * .125

- The optimization is done with one independent ply number variable y1. The expression y1 * .125 outputs a thickness value. A DLINK entry will relate the thickness variables (x1, x2, x3 and x4) to the thickness from expression y1 * .125.



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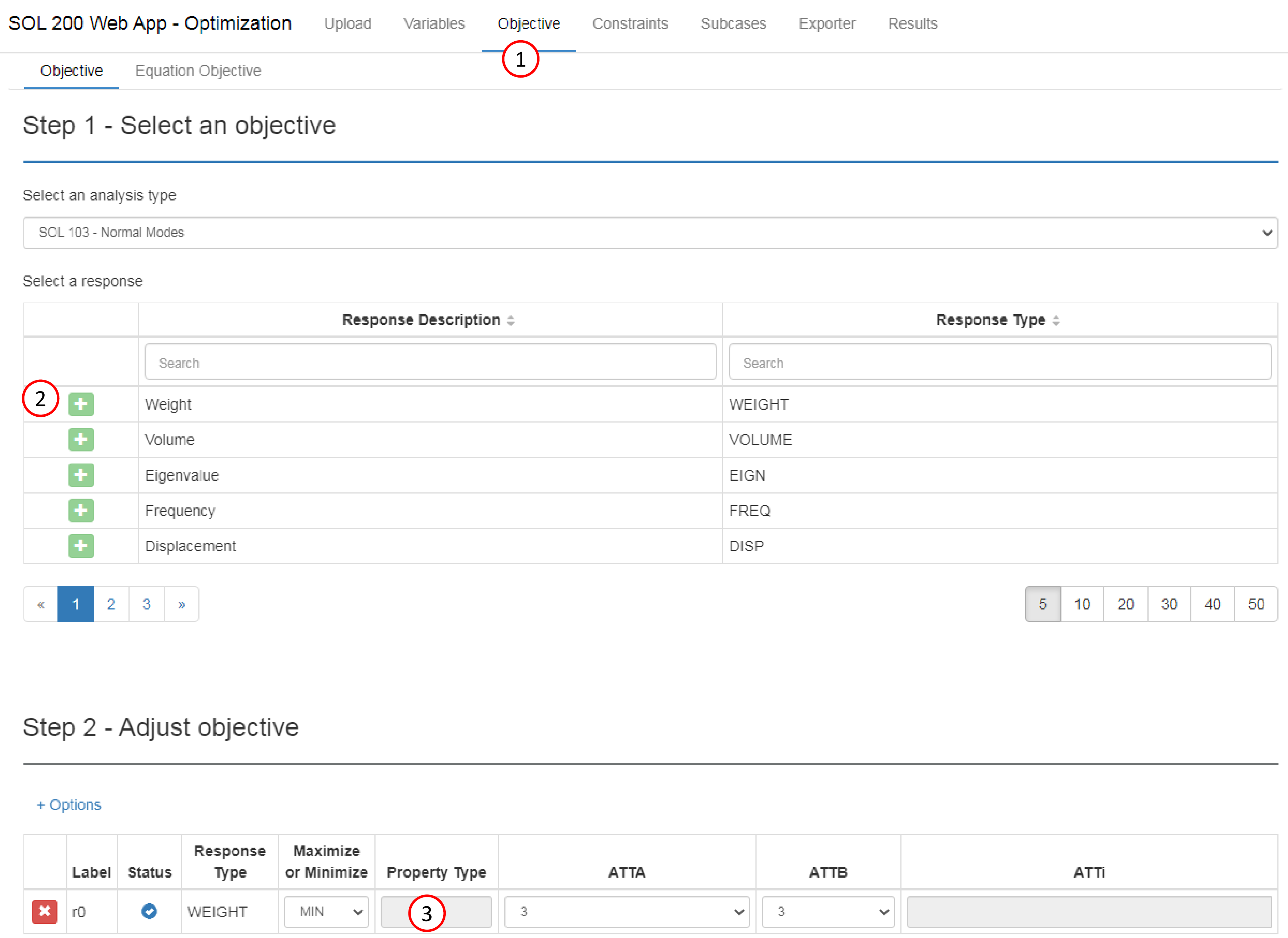
Create Design Objective

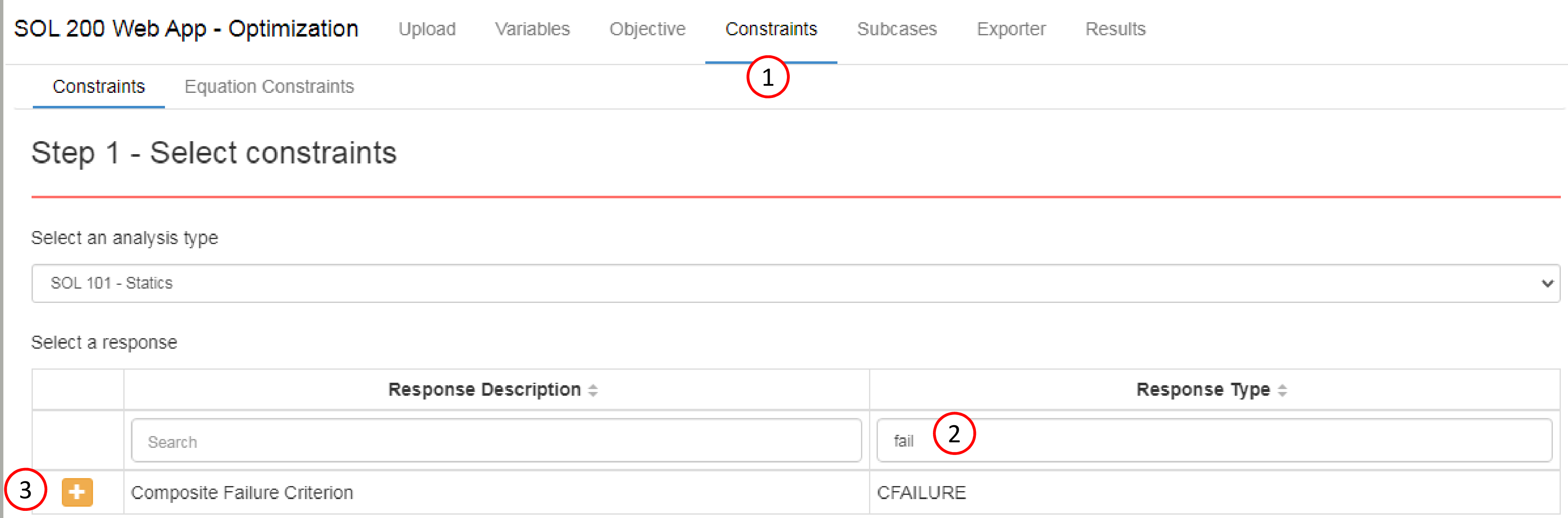
1. Click Objective
2. Select the plus (+) icon for weight
3. The objective has been set to minimize the weight, no further modification is necessary

- The objective must always be a single and global response. A response such as weight and volume are single responses, are independent of load case, and can be used as an objective. Other responses require special care when set as an objective. For example, if the objective is stress, only the stress of a single component, e.g. von Mises, of a single element, of a single load case may be used.



Create Design Constraints

1. Click Constraints
2. In the search box, type ‘fail’
3. Select the plus(+) icon for Composite Failure Criterion 8 times



Create Design Constraints

1. Navigate to section Step 2 – Adjust constraints
2. Click 10 on the pagination bar to display at most 10 rows in the table
3. Ensure 8 responses for the failure index have been created
4. Configure the following for all responses
   - Property Type: PCOMP
   - ATTA: 5 – Failure Index(FP) for direct stresses
   - ATTi: 1
   - Lower Allowed Limit: blank
   - Upper Allowed Limit: .95
5. For each response's ATTB, use the following layer numbers:
   - r1, ATTB: 1
   - r2, ATTB: 2
   - r3, ATTB: 3
   - r4, ATTB: 4
   - r5, ATTB: 15
   - r6, ATTB: 16
   - r7, ATTB: 17
   - r8, ATTB: 18

- The outer plies correspond to layers 1, 2, 3, 4, 15, 16, 17, 18. Typically, the highest ply stresses, strain or failure indices occur in the outer plies, so the failure indices are constrained only for the outer plies.

Step 2 - Adjust constraints (1)

+ Options

(4)

	Label	Status	Response Type	Property Type	ATTA	ATTB	ATTi	Lower Allowed Limit	Upper Allowed Limit
	Se	Sea	Search	Search	Search	Search	Search	Search	Search
✖	r1	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	1	1	Lower	.95
✖	r2	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	2	1	Lower	.95
✖	r3	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	3	1	Lower	.95
✖	r4	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	4	1	Lower	.95
✖	r5	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	15	1	Lower	.95
✖	r6	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	16	1	Lower	.95
✖	r7	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	17	1	Lower	.95
✖	r8	✔	CFAILURE	PCOMP	5 - Failure Index(FP) for direct stre:	18	1	Lower	.95

(3) (5)

5 | 10 | 20 | 30 | 40 | 50

(2)

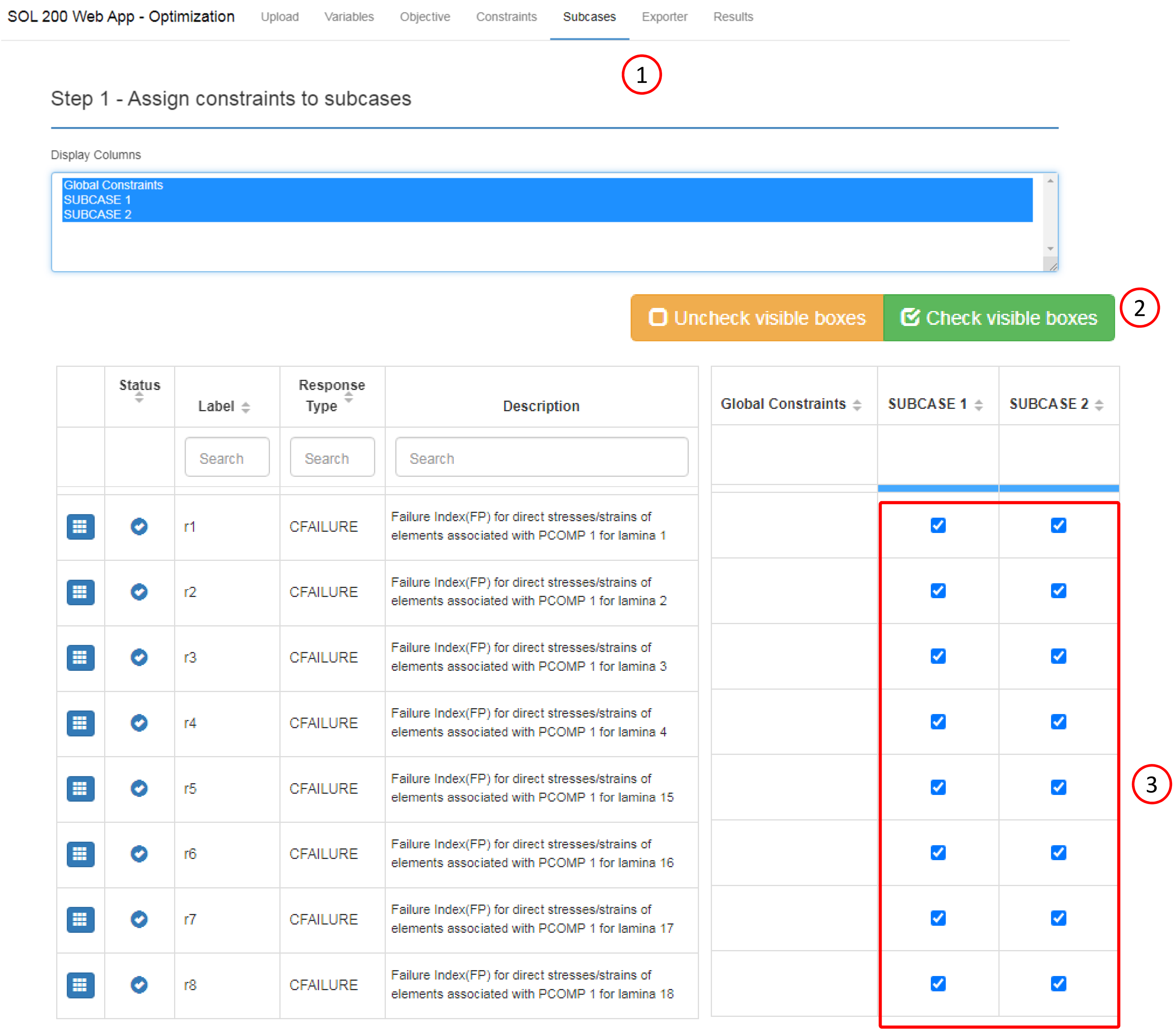
Assign Constraints to Load Cases (SUBCASES)

1. Click Subcases
2. Click Check visible boxes
3. Ensure the indicated checkboxes are marked. The design constraints have been assigned to subcase 1 and 2.

- The r1 and r2 constraints have been assigned to SUBCASE 1 and SUBCASE 2
- When hundreds of SUBCASEs must be configured, the following options expedite the process:

Uncheck visible boxes

Check visible boxes



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"

SOL 200 Web App - Optimization | Upload | Variables | Objective | Constraints | Subcases | Exporter (1) | Results

BDF Output - Model

```
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

ECHO = PUNCH(NEWBULK)
$ Direct Text Input for Global Case Control Data
   DESOBJ(MIN) = 8000000
   $ DESGLB Slot
   $ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
SUBCASE 1
   ANALYSIS = STATICS
   DESSUB = 40000001
   $ DRSPAN Slot
   SUBTITLE=Load Case 1
   SPC = 2
   LOAD = 2
   DISPLACEMENT(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
```

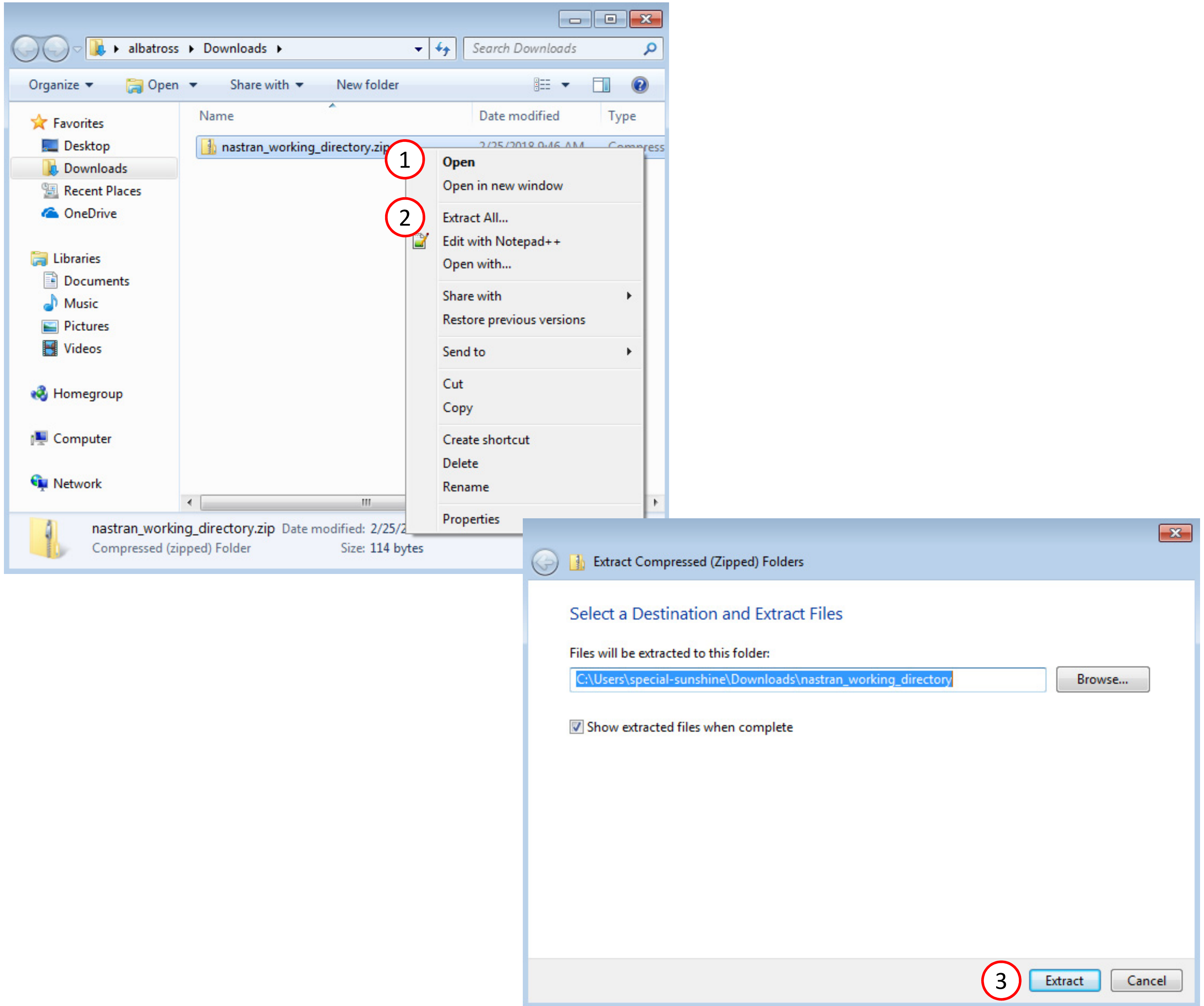
Download BDF Files

Download BDF Files (2)

Perform the Optimization with Nastran SOL 200

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

- Always extract the contents of the ZIP file to a new, empty folder.



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

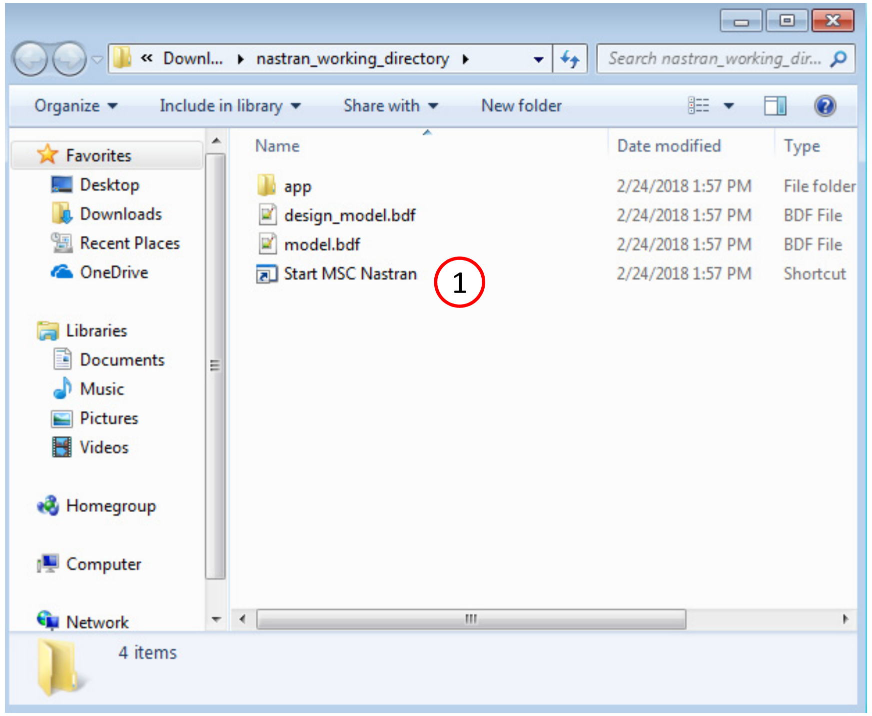
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the 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.

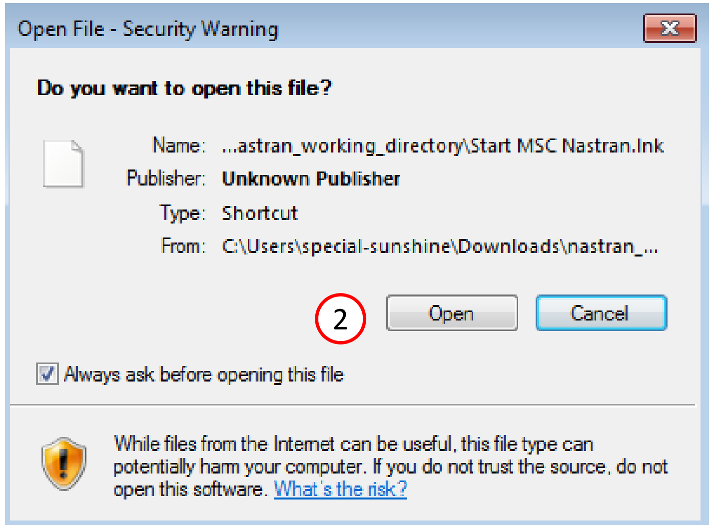
Using Linux?

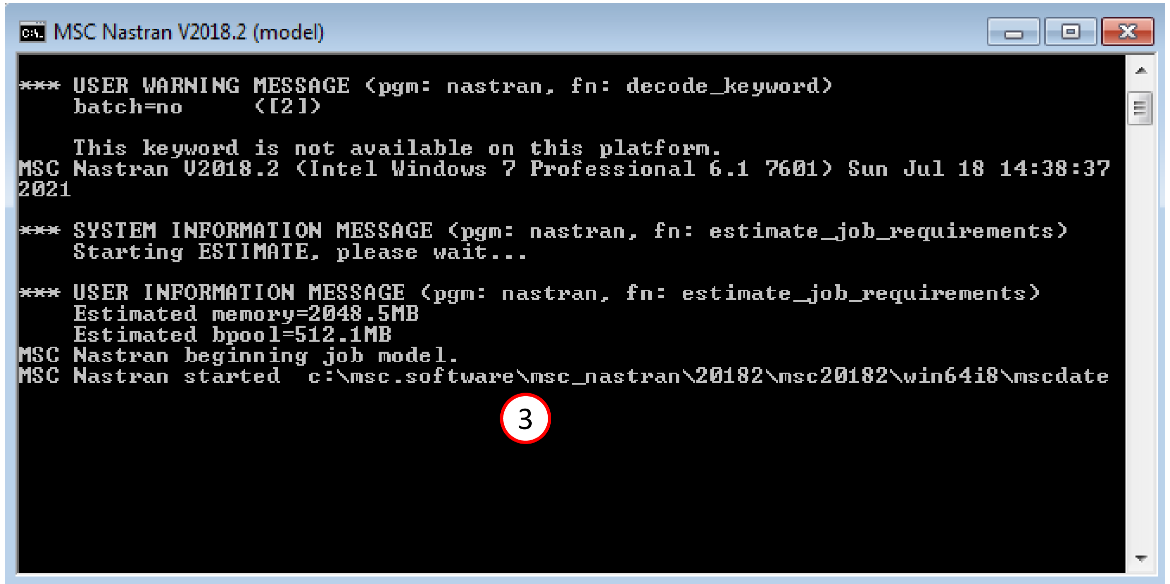
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
   cd ./nastran_working_directory
3) Use this command to start the process
   ./Start_MSC_Nastran.sh

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







Status

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

- 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.

SOL 200 Web App - Status

Python MSC Nastran

Status

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

Review Optimization Results

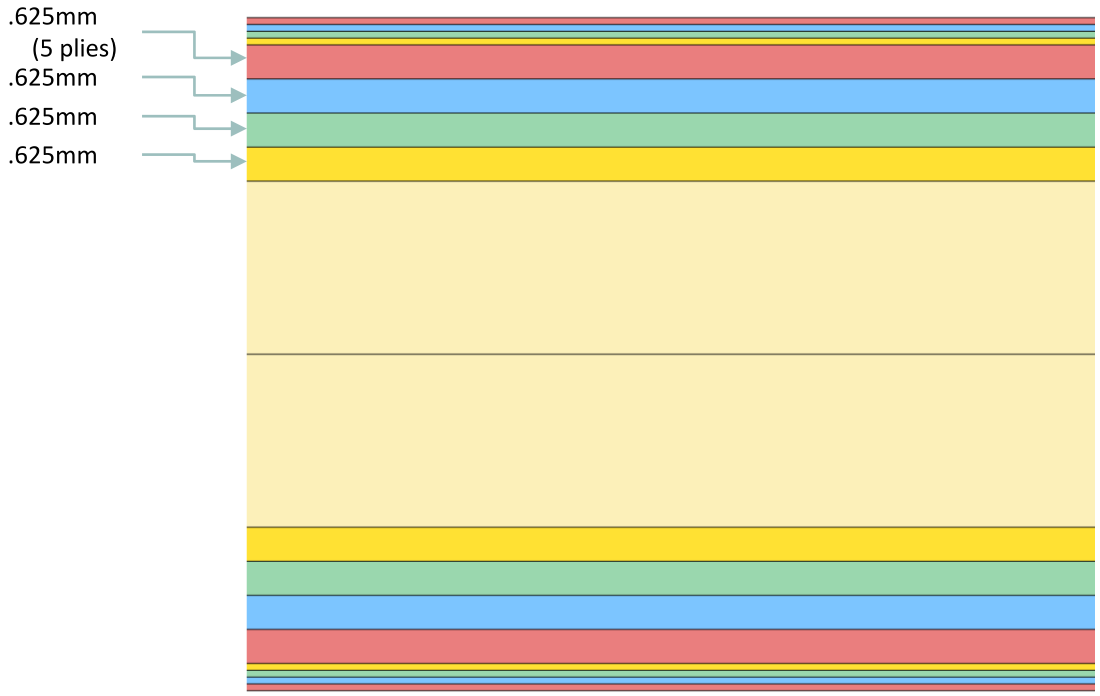
After MSC Nastran is finished, the results will be automatically uploaded.

1. Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.
2. The final value of objective, normalized constraints (not shown) and design variables can be reviewed.
3. From this optimization, it is found that 2 plies are needed for the 90°, 45°, -45° and 0° layers.

Results

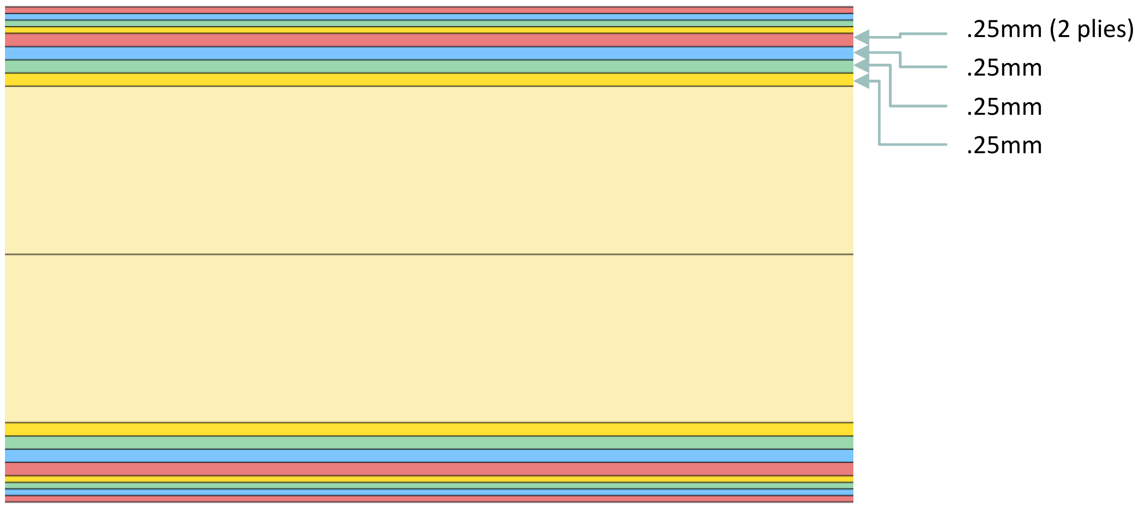
Before Optimization

- Weight: 5.054999E-05
- Max Failure Index of Outer Plies: .235



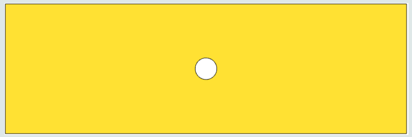
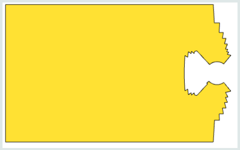
After Optimization

- Weight: 2.825148E-05
- Max Failure Index of Outer Plies: .934



Baseline Model

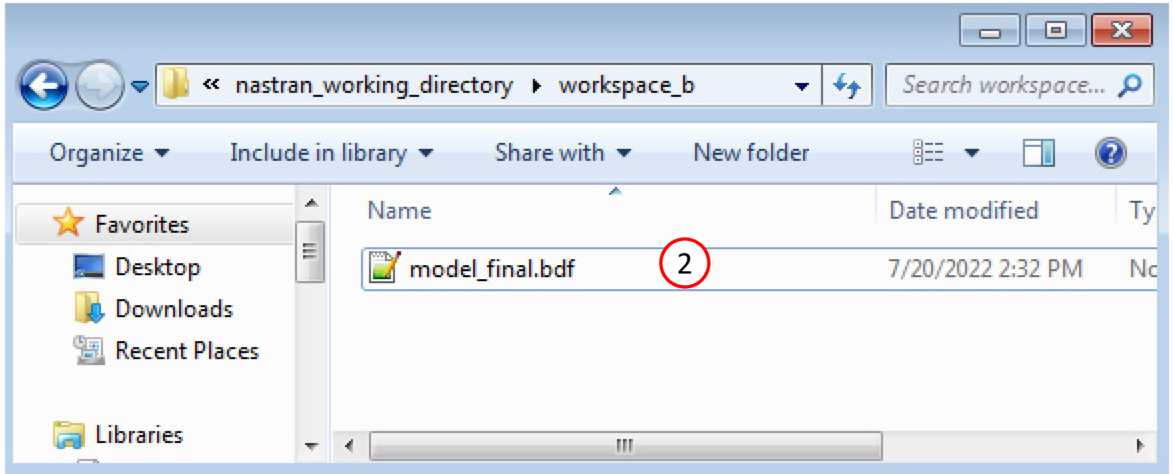
- The composite in this tutorial currently uses continuous plies that span the entire coupon. A future tutorial will demonstrate how to optimize the ply shapes.
- This ply number optimization was performed to establish a baseline of results. The optimal mass, 2.83E-5, and max failure index, .934, from this tutorial are recorded in the table shown. The results after ply shape optimization will be compared with this baseline model.

	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		
Mass of Non-design Region (Core)	5.952966E-06		
Mass of Design Region (Plies)	**2.229851E-05**		
Max Failure Index , Subcase 1	.905 (OK)		
Max Failure Index, Subcase 2	.934 (OK)		
Example of ply shape			

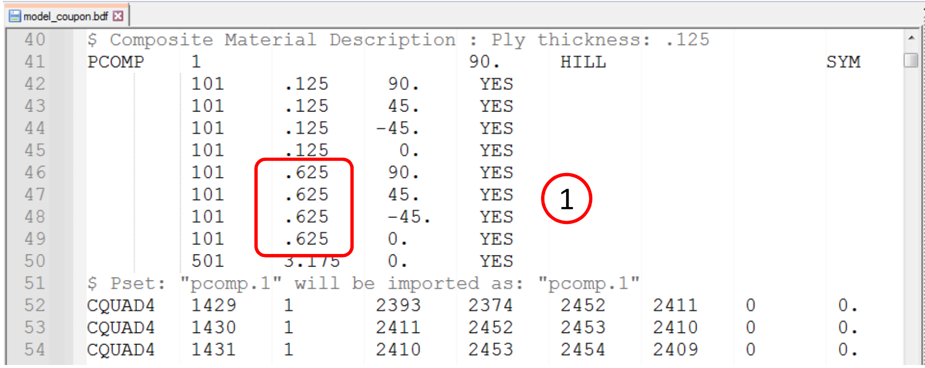
Update the Original Model

1. The original input files, e.g. DAT, BDF, etc., contains the original values for the designed properties. These original values must be updated to use the new and optimized values.
2. A new BDF file has been created in nastran_working_directory/workspace_b/model_final.bdf.
3. The file model_final.bdf is a copy of the original input files but the original values for the designed properties have been updated to use the optimized values.

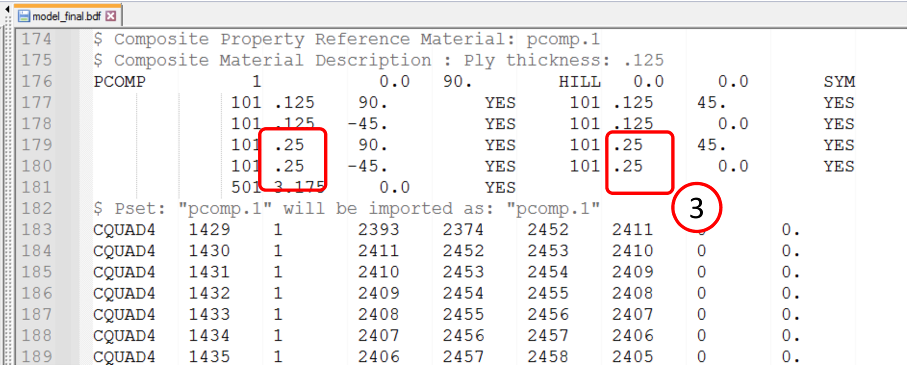
- If you were using multiple INCLUDE files, model_final.bdf is a combination of all INCLUDE files. The next few slides discuss an alternative method of using the PCH to BDF web app to update the values for the designed properties while preserving separate INCLUDE files.



Original Input Files

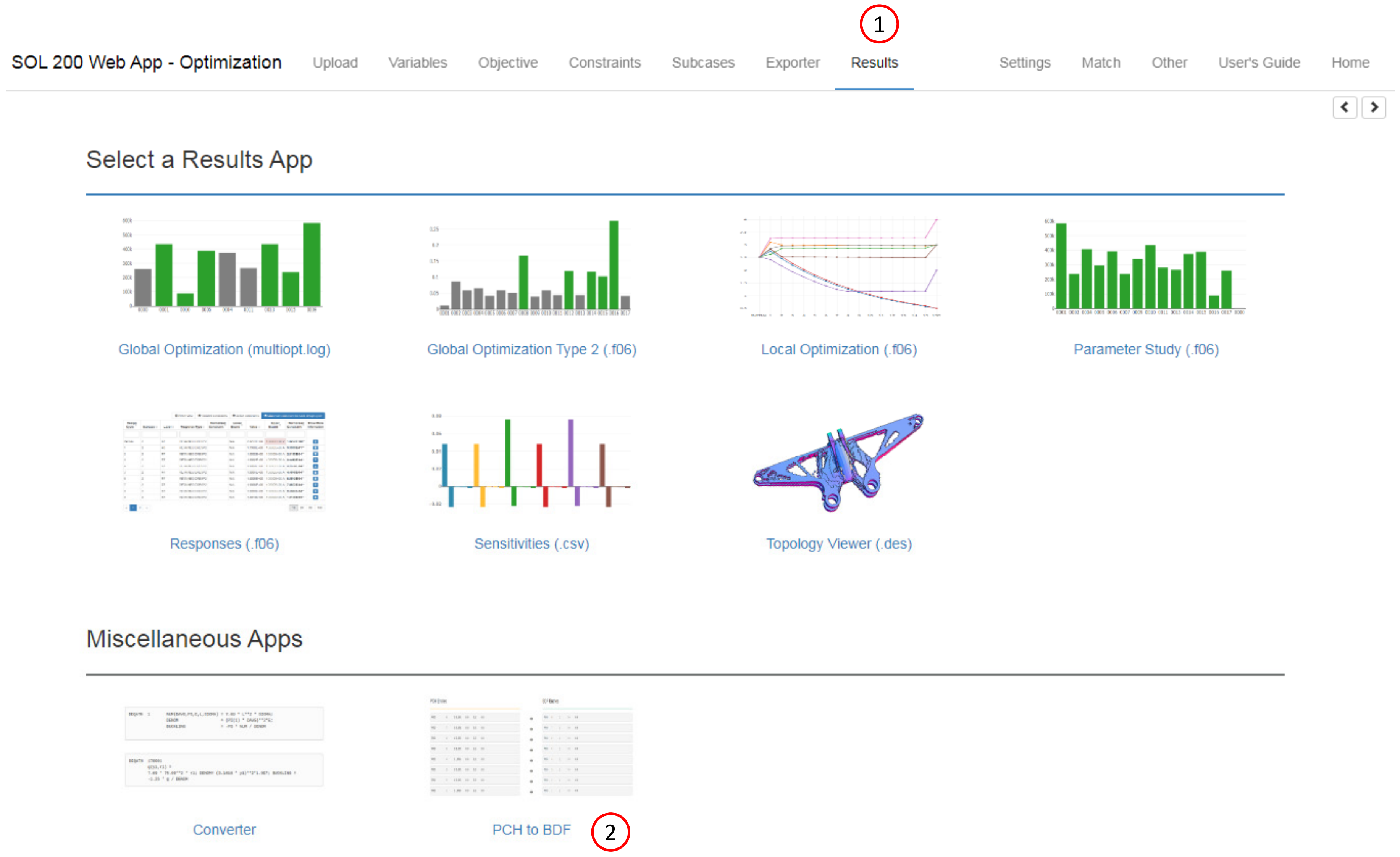


Updated BDF File (model_final.bdf)



Update the Original Model

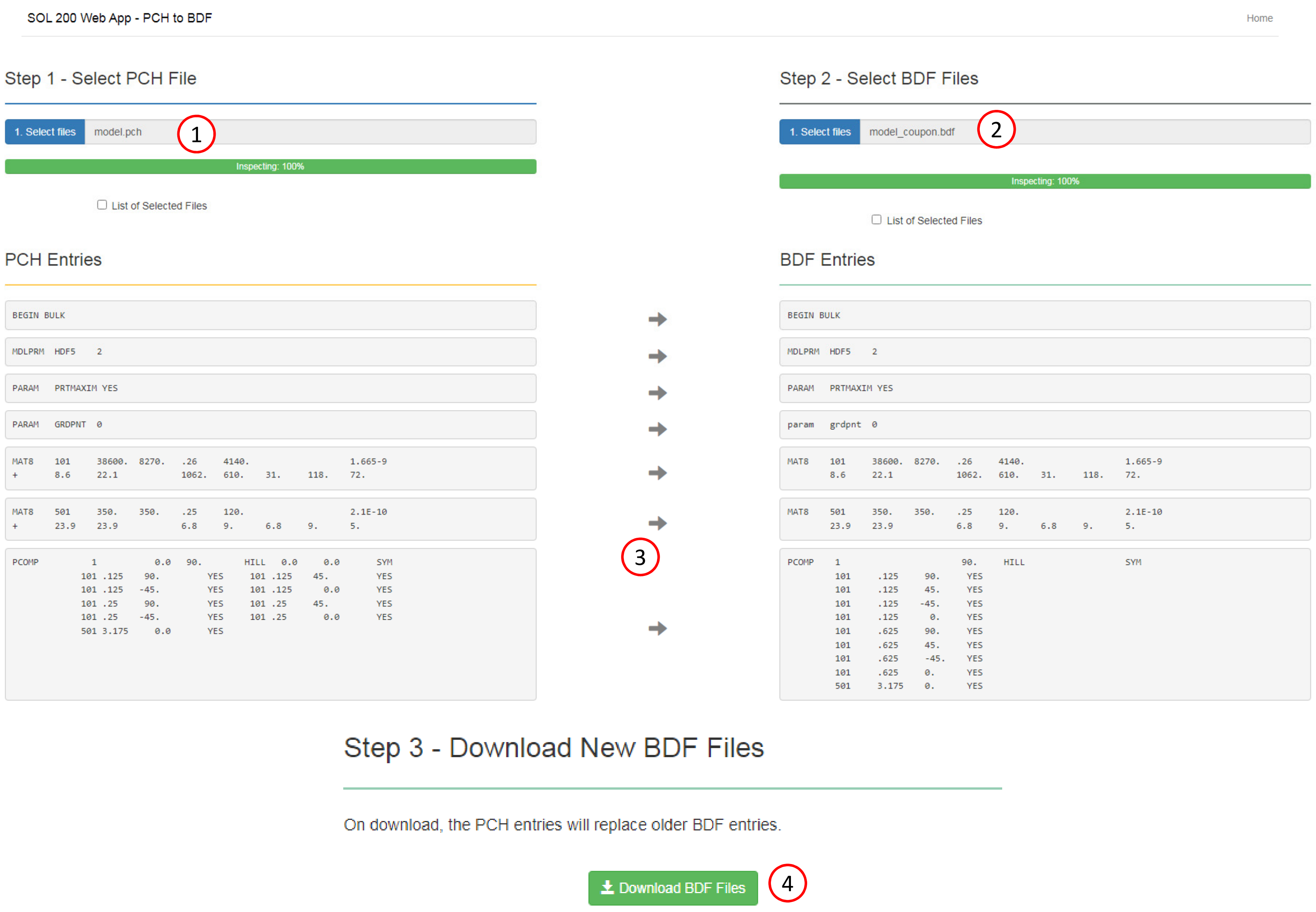
1. Click Results
2. Click PCH to BDF



Update the Original Model

The original .bdf/.dat file has old information about the properties. The properties will be updated.

1. Select the model.pch file
2. Select the original file: model_coupon.bdf
3. A summary of updates that will be performed are shown
4. Click Download and a new updated BDF file is downloaded



Update the Original Model

1. Note the entries have been updated with the optimized properties

model_coupon.bdf

```
$ Composite Material Description : Ply thickness: .125
PCOMP   1                       90.     HILL                            S
                101     .125    90.     YES
                101     .125    45.     YES
                101     .125    -45.    YES
                101     .125    0.      YES
                101     .625    90.     YES
                101     .625    45.     YES
                101     .625    -45.    YES
                101     .625    0.      YES
                501     3.175   0.      YES
$ Pset: "pcomp.1" will be imported as: "pcomp.1"
CQUAD4  1429    1       2393    2374    2452    2411    0
CQUAD4  1430    1       2411    2452    2453    2410    0
CQUAD4  1431    1       2410    2453    2454    2409    0
CQUAD4  1432    1       2409    2454    2455    2408    0
CQUAD4  1433    1       2408    2455    2456    2407    0
CQUAD4  1434    1       2407    2456    2457    2406    0
```

Original BDF/DAT File

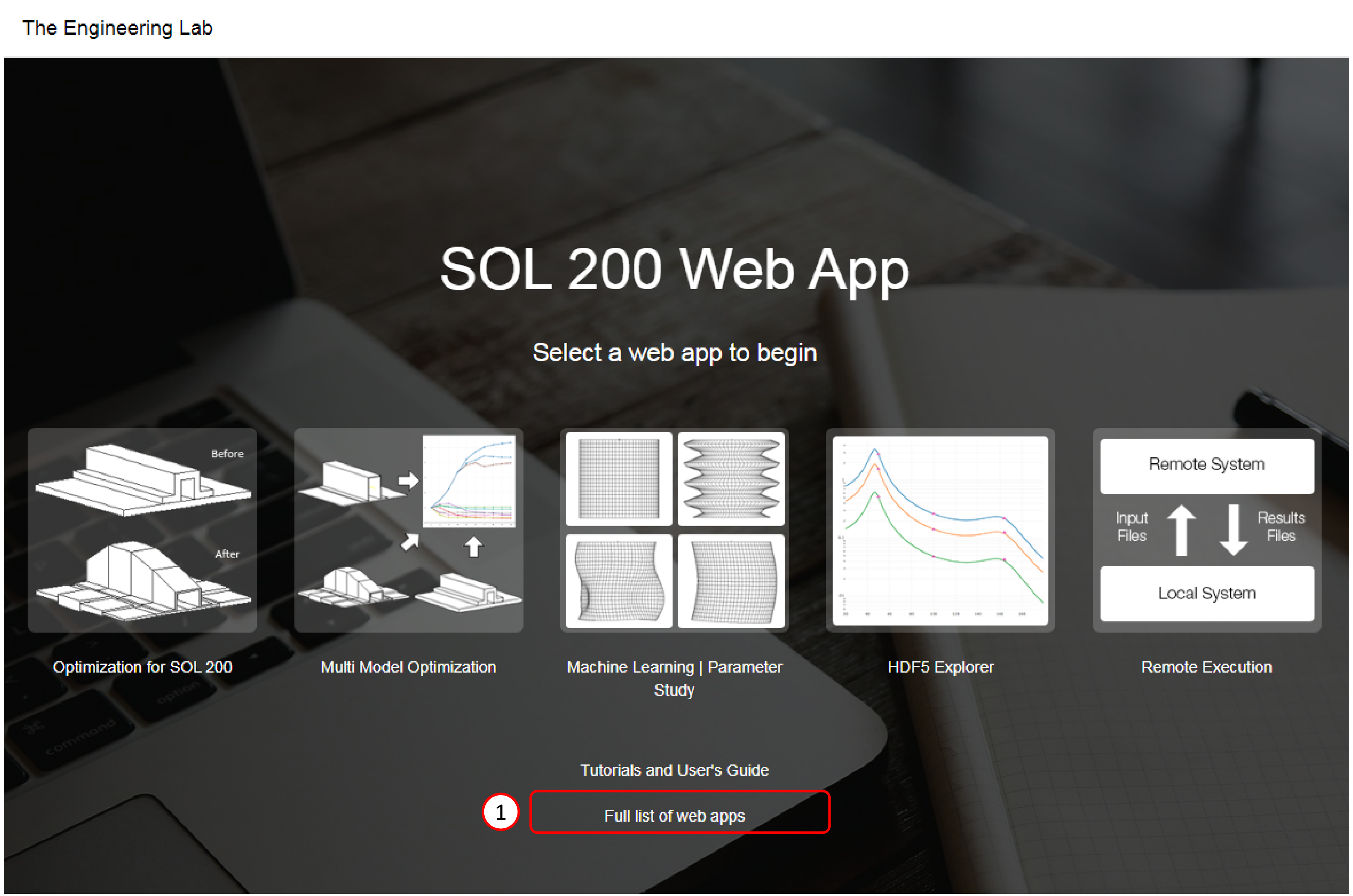
model_coupon.bdf

```
$ Composite Material Description : Ply thickness: .125
PCOMP          1     0.0 90.         HILL   0.0       0.0        SY
             101 .125    90.         YES     101 .125 45.        YE
             101 .125   -45.         YES     101 .125   0.0      YE
             101 .25     90.         YES     101 .25  45.        YE
             101 .25    -45.         YES     101 .25    0.0      YE
             501 3.175   0.0         YES
$ Pset: "pcomp.1" will be imported as: "pcomp.1"
CQUAD4  1429    1       2393    2374    2452    2411    0       0.
CQUAD4  1430    1       2411    2452    2453    2410    0       0.
CQUAD4  1431    1       2410    2453    2454    2409    0       0.
CQUAD4  1432    1       2409    2454    2455    2408    0       0.
CQUAD4  1433    1       2408    2455    2456    2407    0       0.
CQUAD4  1434    1       2407    2456    2457    2406    0       0.
CQUAD4  1435    1       2406    2457    2458    2405    0       0.
CQUAD4  1436    1       2405    2458    2459    2404    0       0.
CQUAD4  1437    1       2404    2459    2460    2403    0       0.
CQUAD4  1438    1       2403    2460    2461    2402    0       0.
```

Downloaded BDF/DAT File

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

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For access, visit

the-engineering-lab.com

or contact

christian@ the-engineering-lab.com

Upload BDF Files

1. Click Upload BDF
2. Click Select files
3. Click workspace_b
4. Select the indicated files
5. Click Open
6. Click Upload files
7. Click Background Color (Optional)

Content only available to professional engineers and students.

For access, visit

the-engineering-lab.com

or contact

christian@ the-engineering-lab.com

Display Plies

1. Click Model Display Panel
2. Click Iso 3
3. Right click and hold the right mouse button, and move the mouse to translate the model into view.
4. Click the indicated icon
5. Click the indicated icon
6. Click the indicated icon to recolor the plies
7. The ply thickness is now displayed

Content only available to professional engineers and students.

For access, visit

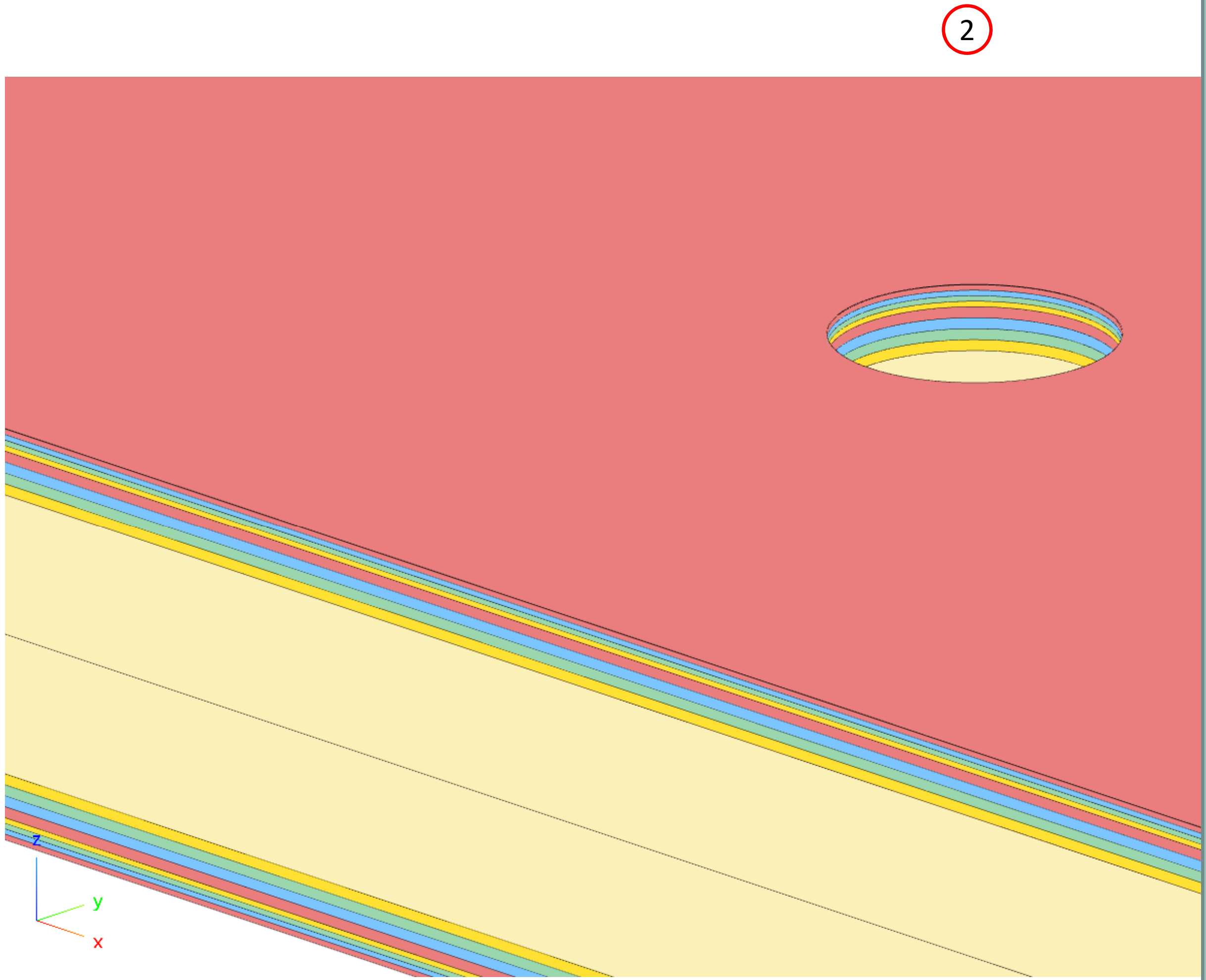
the-engineering-lab.com

or contact

christian@ the-engineering-lab.com

Display Plies

1. Click Model Display Panel
2. Rotate and/or zoom in to the model to view the plies



End of Tutorial

Appendix

Appendix Contents

- What is a layer on the PCOMP entry?
- PCOMP Format for Optimization
  - Comments on Ply Output
  - Consideration of Initial Stacking Sequence When Performing Composite Ply Shape And Ply Number Optimization Under Bending Loads
- Why is the ply number optimization configured to start with 1 ply instead of the original 5 plies?

What is a layer on the PCOMP entry?

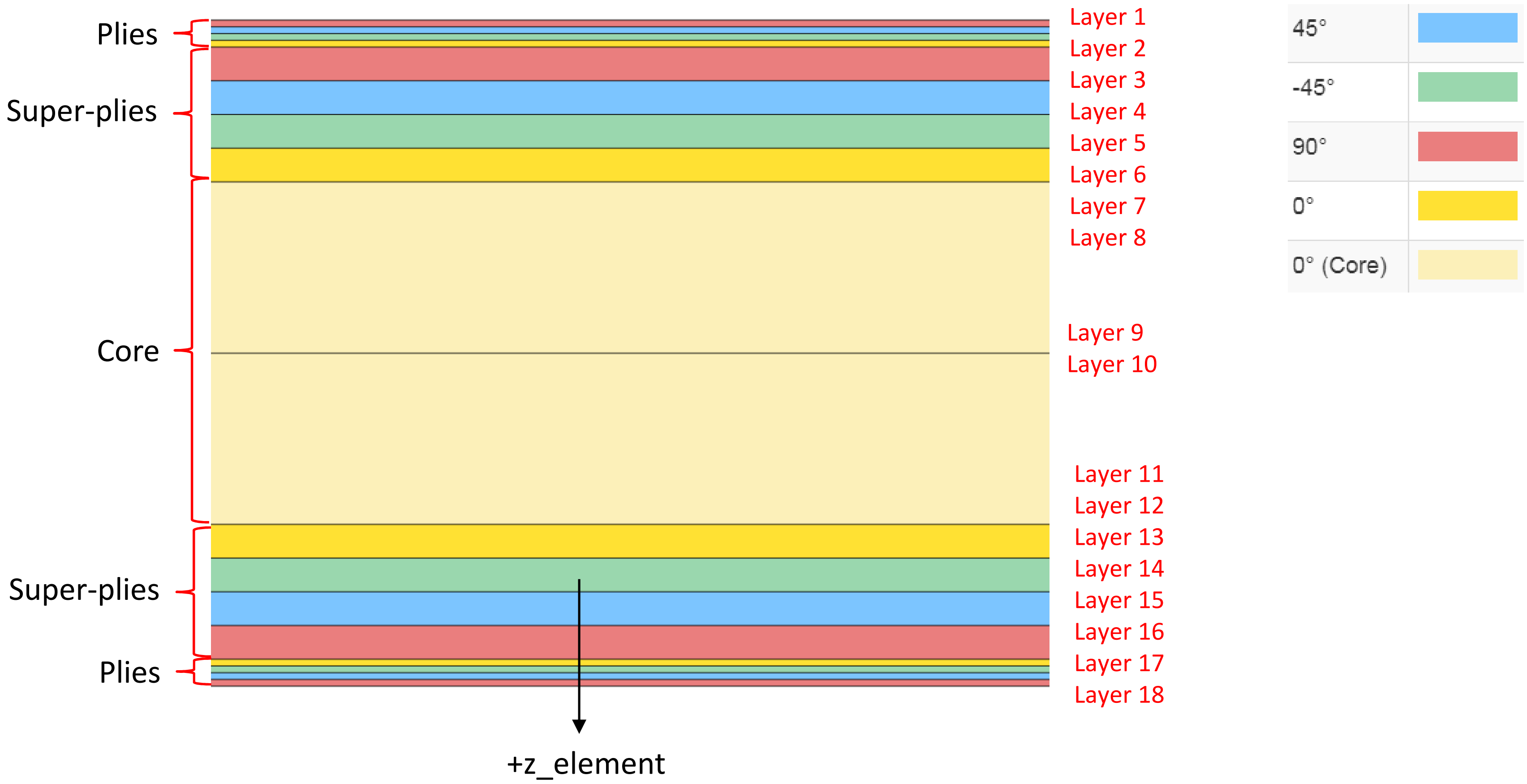
What is a layer on the PCOMP entry?

The PCOMP or PCOMPG entry is used to define layers in a composite. The layers could correspond to plies, super-plies or a core.

- Plies are layers that have a thickness equal to an actual ply. These layers will be referred to as *ply layers*.
- A super-ply is a layer that has a thickness equal to multiple plies. These layers will be referred to as *super-ply layers*.
- A core layer corresponds to the core material and is usually the most inner layer. These layers will be referred to as *core layers*.

During an optimization, only the thickness of the super-ply or core layers will vary. The thickness of the ply layers will never change during an optimization.

For this workshop, a ply has a thickness of 0.125mm. For the PCOMP entry used in this workshop, layers 1, 2, 3, 4, 15, 16, 17 and 18 are ply layers. Layers 5, 6, 7, 8, 11, 12, 13 and 14 are super-ply layers. Each of these super-ply layers correspond to 5 plies (5 plies * .125mm = .625mm). Layers 9 and 10 are the core layers.




```
PCOMP,1,,,90.,,,,SYM
        101     .125    90.     YES Layer 1
        101     .125    45.     YES Layer 2
        101     .125   -45.     YES Layer 3
        101     .125     0.     YES Layer 4
        101     .625    90.     YES Layer 5
        101     .625    45.     YES Layer 6
        101     .625   -45.     YES Layer 7
        101     .625    0.      YES Layer 8
        501     3.175   0.      YES Layer 9
```

PCOMP Format for Optimization

PCOMP Format for Optimization

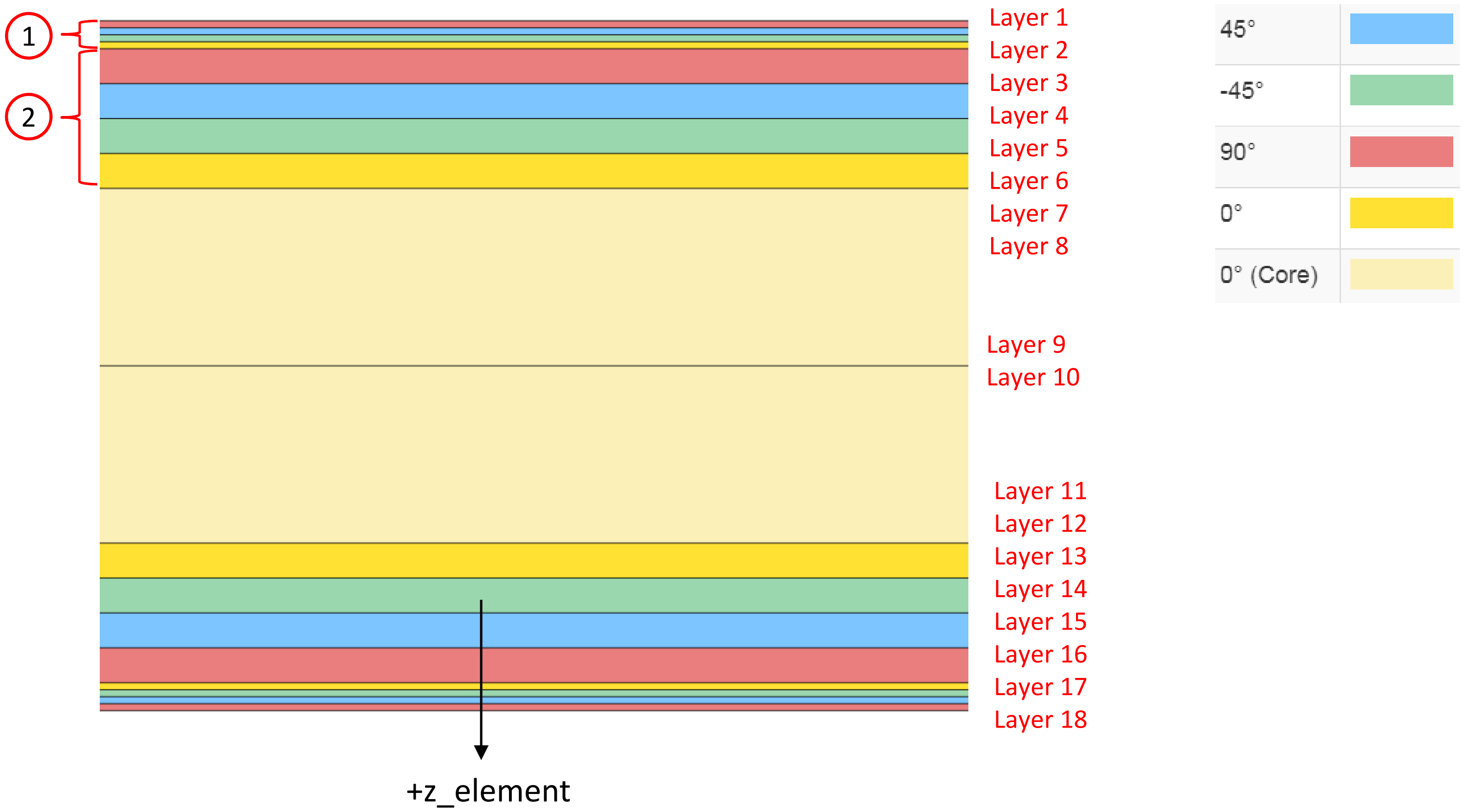
When optimizing the layer thicknesses of a PCOMP entry, two questions must be asked. The answers to these questions will decide the format of the PCOMP entry to use during optimization.

1. Will ply outputs such as ply stress, ply strain, failure index or strength ratio need to be considered?
   - Yes – Place one ply layer for each unique angle on the top and bottom of the laminate. Monitor or constrain the ply outputs for the outermost ply layers. In this workshop, the ply layers are layers 1, 2, 3, 4, 15, 16, 17 and 18. The failure indices of the ply layers are constrained.
   - No – Ply layers 1, 2, 3, 4, 15, 16, 17 and 18 are not necessary. The super-ply layers 5, 6, 7, 8, 11, 12, 13, 14 and the core layers 9 and 10 should remain.

For more information, see section *Comments on Ply Output.*

2. Is the LAM field blank, SYM or BEND?
   - Yes – The 90° super-ply layer should be furthest from the midplane and 0° super-ply layer should be closest to the midplane.
   - No – The stacking sequence does not require special placement.

For more information, see section *Consideration of Initial Stacking Sequence When Performing Composite Ply Shape And Ply Number Optimization Under Bending Loads.*

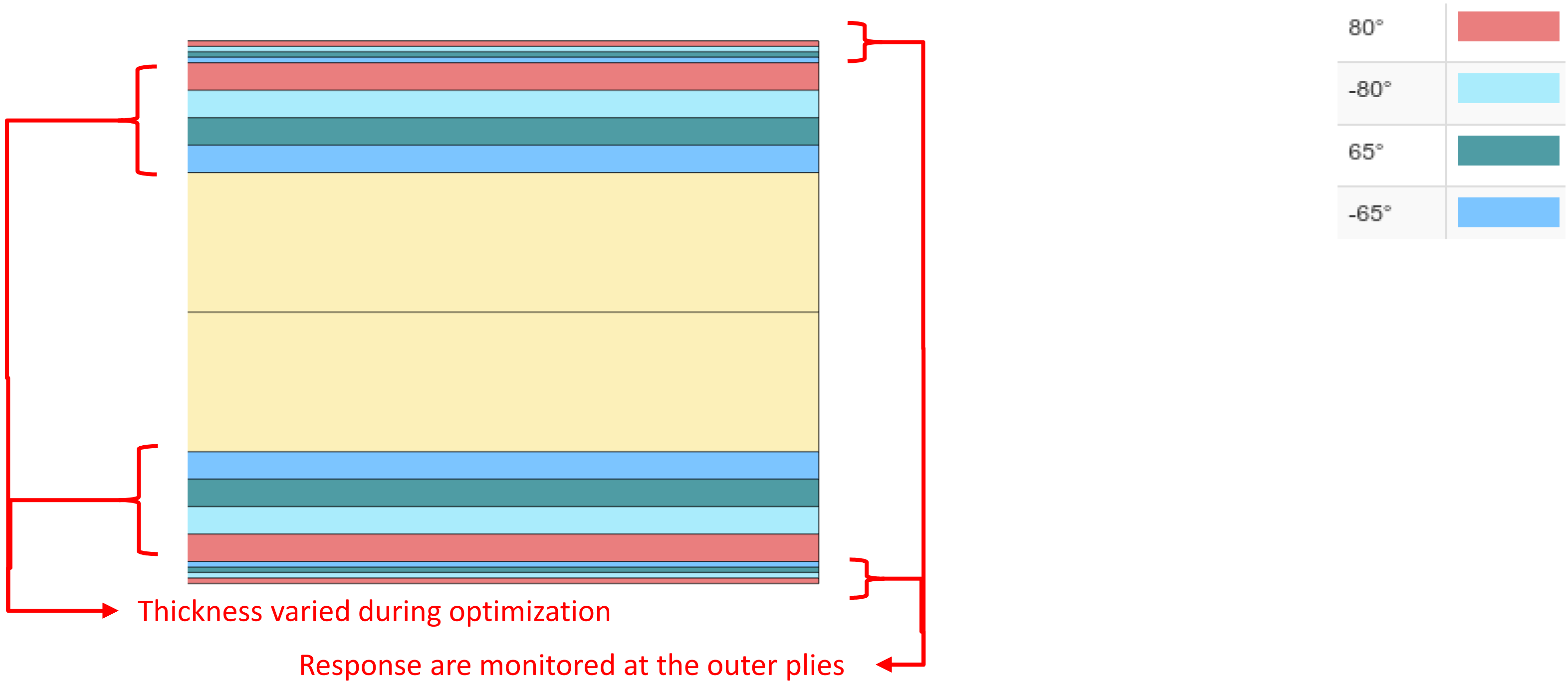



```
PCOMP,1,,,90.,,,,SYM
        101     .125    90.     YES Layer 1
        101     .125    45.     YES Layer 2
        101     .125   -45.     YES Layer 3
        101     .125     0.     YES Layer 4
        101     .625    90.     YES Layer 5
        101     .625    45.     YES Layer 6
        101     .625   -45.     YES Layer 7
        101     .625    0.      YES Layer 8
        501     3.175   0.      YES Layer 9
```

PCOMP Format for Optimization

This is another example which uses different angles ±80 and ±65. The same procedure is followed.

- The outer layers are ply layers and have a thickness equal to the actual ply thickness of .125mm. These ply layers will be used to monitor the failure index.
- The interior super-ply layers, those with a thickness of .625, will be used for ply number optimization and ply shape optimization.




```
PCOMP,2,,,90.,,,,SYM
           101     .125     80.      YES  Layer 1
           101     .125    -80.      YES  Layer 2
           101     .125     65.      YES  Layer 3
           101     .125    -65.      YES  Layer 4
           101     .625     80.      YES  Layer 5
           101     .625    -80.      YES  Layer 6
           101     .625     65.      YES  Layer 7
           101     .625    -65.      YES  Layer 8
           501     3.175    0.       YES  Layer 9
```

Thickness varied during optimization

Response are monitored at the outer plies. Thicknesses are NOT varied.

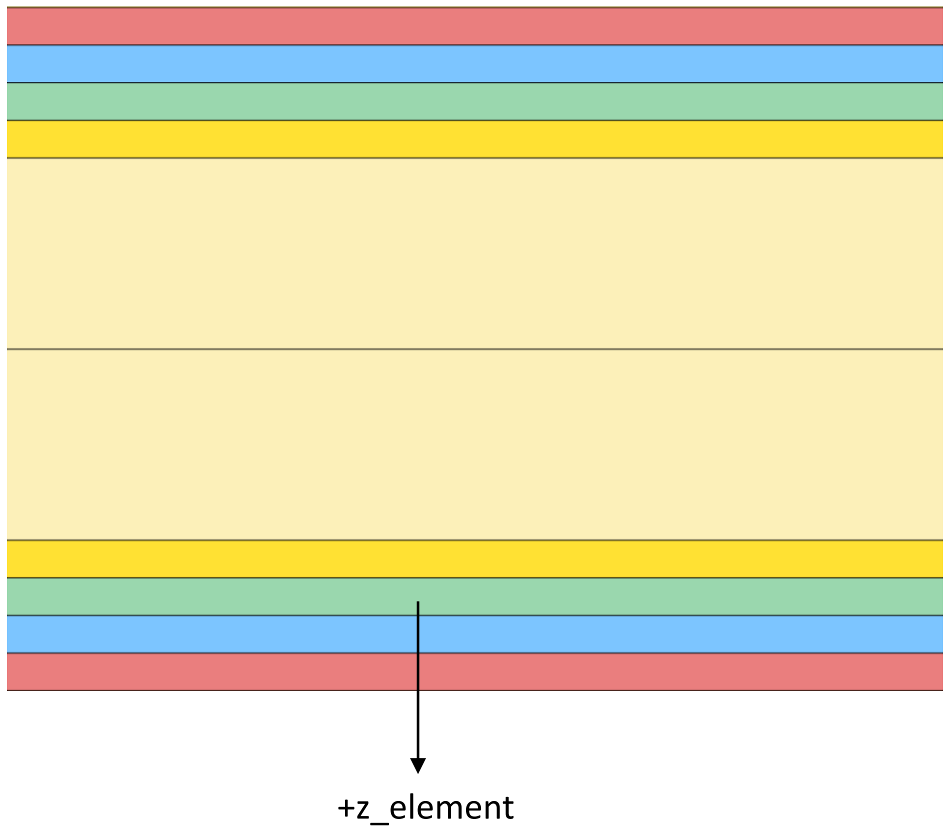
PCOMP Format for Optimization

Consider this optimization. Minimize the mass, constrain the first natural frequency and vary the thickness of the super-ply layers.

1. Since ply outputs are not considered in this optimization, ply layers do not need to be defined.
2. LAM is SMCORE. The sequence of the super-ply layers does not need special preparation.

The displayed PCOMP entry maybe used during optimization.

45°	
-45°	
90°	
0°	
0° (Core)	




```
PCOMP,3,,,90.,,,,SMCORE
         101      .625     90.      YES
         101      .625     45.      YES
         101      .625     -45.     YES
         101      .625     0.       YES
         501      6.35     0.       YES
```

Comments on Ply Output

Comments on Ply Output

Ply outputs such as ply stress, ply strain and failure index are calculated at the midplane of each layer.

Consider laminates A, B and C, all of which have the same total thickness of 5.0. Since the LAM=SYM option is used, the total thickness is 2.5*2=5.0. The maximum failure index will vary depending on how the PCOMP entry is configured.

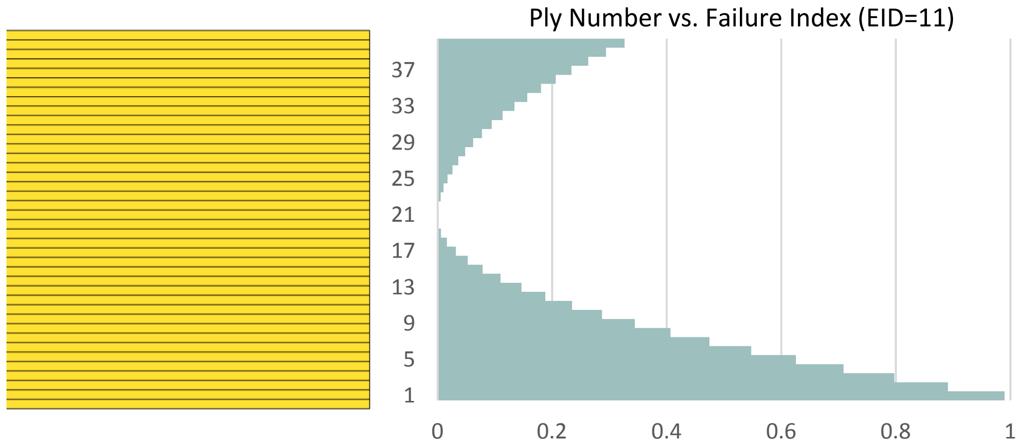
Laminate	Maximum Failure Index
A	~1.0 in layer 1
B	~0.3 in layer 1
C	~1.0 in layer 1

Laminates A and C output a maximum failure index of 1.0, but laminate B outputs a maximum failure index of 0.3. The ply output of laminate B is misleading.

If ply outputs are to be constrained during the optimization:

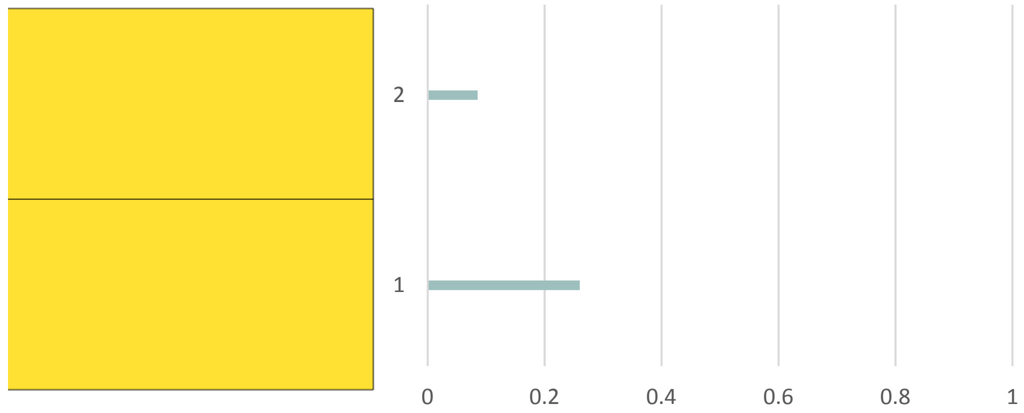
1. Set the thickness of the outer layers to actual ply thickness values. Said another way, the outer layers should be *ply layers*.
2. Recall the thickness of ply layers will not change during the optimization. Only the thickness of super-ply or core layers will change.
3. Constrain only the ply outputs of the outermost ply layers.

A



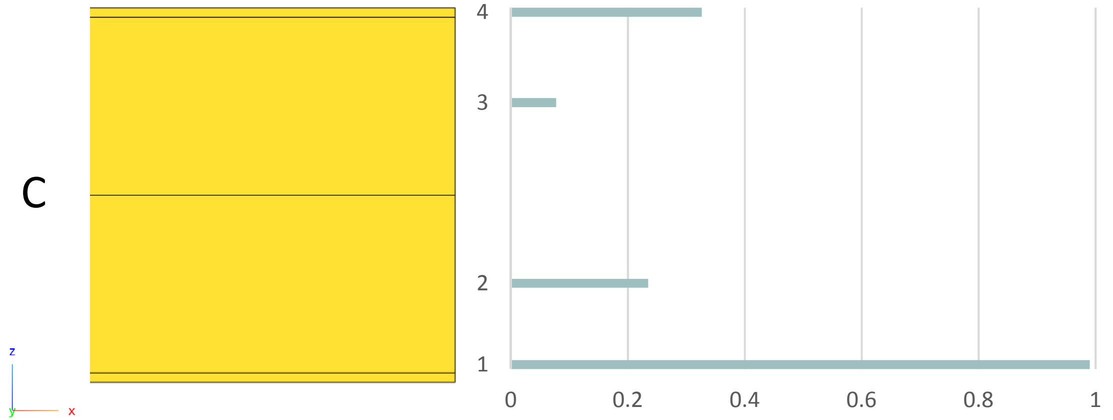

```
PCOMP, 1,,,90., HILL,,SYM
          101     .125    0.        YES
          101     .125    0.        YES
          101     .125    0.        YES
[…] A total of 20 layers are repeated
          101     .125    0.        YES
          101     .125    0.        YES
```

B




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

C



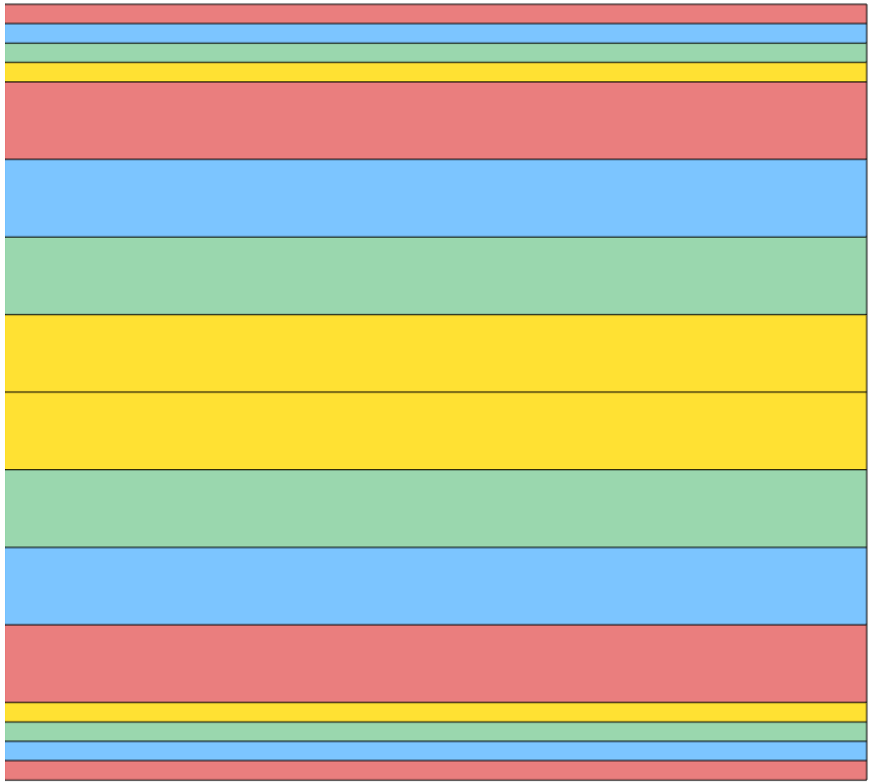

```
PCOMP, 1,,,90., HILL,,SYM
          101     .125    0.        YES
          101    2.375    0.        YES
```

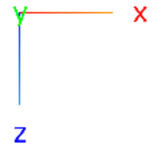
Comments on Ply Output

When layers for other angles exist, such as 90 or 45 degrees, the same procedure should be followed.

1. Set the thickness of the outer layers to actual ply thickness values. Said another way, the outer layers should be *ply layers*.
2. Recall the thickness of ply layers will not change during the optimization. Only the thickness of super-ply or core layers will change.
3. Constrain only the ply outputs of the outermost ply layers.

For the example shown, angle 0, 45, -45 and 90 are used. The ply layers are the outermost layers and their thicknesses will not change during the optimization. The super-ply layers are the innermost layers and their thicknesses will vary during the optimization.





0.	(yellow)
45.	(blue)
-45.	(green)
90.	(red)

```
PCOMP   2                         90.     HILL                SYM
        101     .125    90.       YES
        101     .125    45.       YES
        101     .125    -45.      YES
        101     .125     0.       YES
        101     .5      90.       YES
        101     .5      45.       YES
        101     .5      -45.      YES
        101     .5      0.        YES
```

Plies (first four 101 .125 entries): The thickness of the outer layers remains fixed throughout the entire optimization procedure. → Constrain the ply outputs of the outer layers

Super-plies (last four 101 .5 entries): Create TOMVAR entries for the inner layers and perform ply shape and ply number optimization for these layers only

Consideration of Initial Stacking Sequence When Performing Composite Ply Shape And Ply Number Optimization Under Bending Loads

Before Reading

The following information is relevant only if the following conditions are met.

1. The thickness on a PCOMP entry is optimized AND LAM=blank, LAM=SYM or LAM=BEND.
2. A stacking sequence optimizer considers only manufacturing constraints and does not consider stiffness.

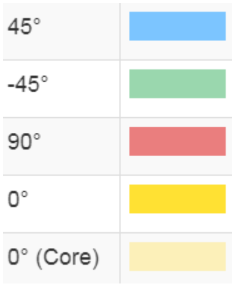
Why optimize [90/45/-45/0] instead of [0/45/-45/90]?

Consider optimizing the super-ply layer thicknesses of a PCOMP entry. The ply layer thicknesses are ignored for now.

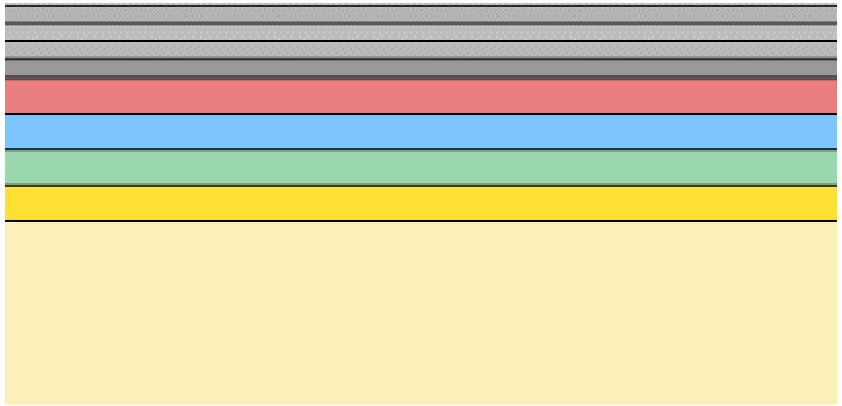
This workshop series optimized super-ply layers 5, 6, 7 and 8, which has sequence [90/45/-45/0]. Some readers may ask why option B is not used, which has sequence [0/45/-45/90]?

The goal of this section is to answer this question.

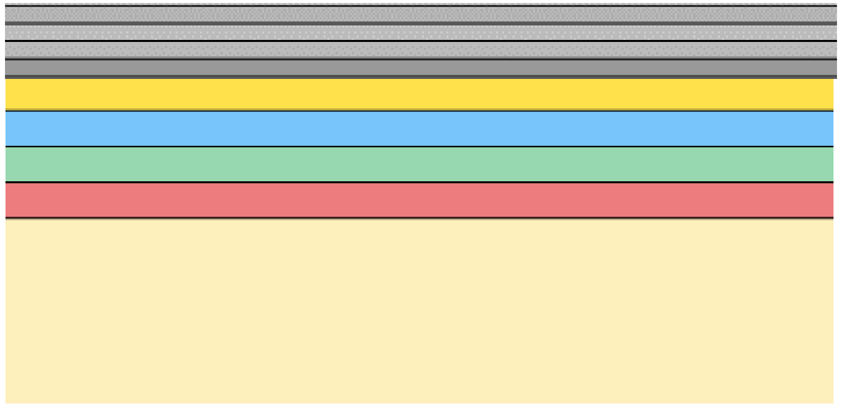
Ply layers 1, 2, 3 and 4 are used to monitor ply outputs such as ply stress, ply strain or failure index, and are ignored on this slide. Layers 1, 2, 3 and 4 are colored gray.



Option A: [90/45/-45/0]



Option B: [0/45/-45/90]



```
PCOMP,1,,,90.,,,,SYM
         101      .125      90.       YES    Layer 1
         101      .125      45.       YES    Layer 2
         101      .125     -45.       YES    Layer 3
         101      .125       0.       YES    Layer 4
         101      .25       90.       YES    Layer 5
         101      .25       45.       YES    Layer 6
         101      .25      -45.       YES    Layer 7
         101      .25       0.        YES    Layer 8
         501      3.175     0.        YES    Layer 9
```

```
PCOMP,1,,,90.,,,,SYM
         101      .125      90.       YES
         101      .125      45.       YES
         101      .125     -45.       YES
         101      .125       0.       YES
         101      .25        0.       YES
         101      .25       45.       YES
         101      .25      -45.       YES
         101      .25       90.       YES
         501      3.175     0.        YES
```

Composite Analysis Model

For this example, a composite strip is optimized.

The composite strip is subjected to 4 moments.

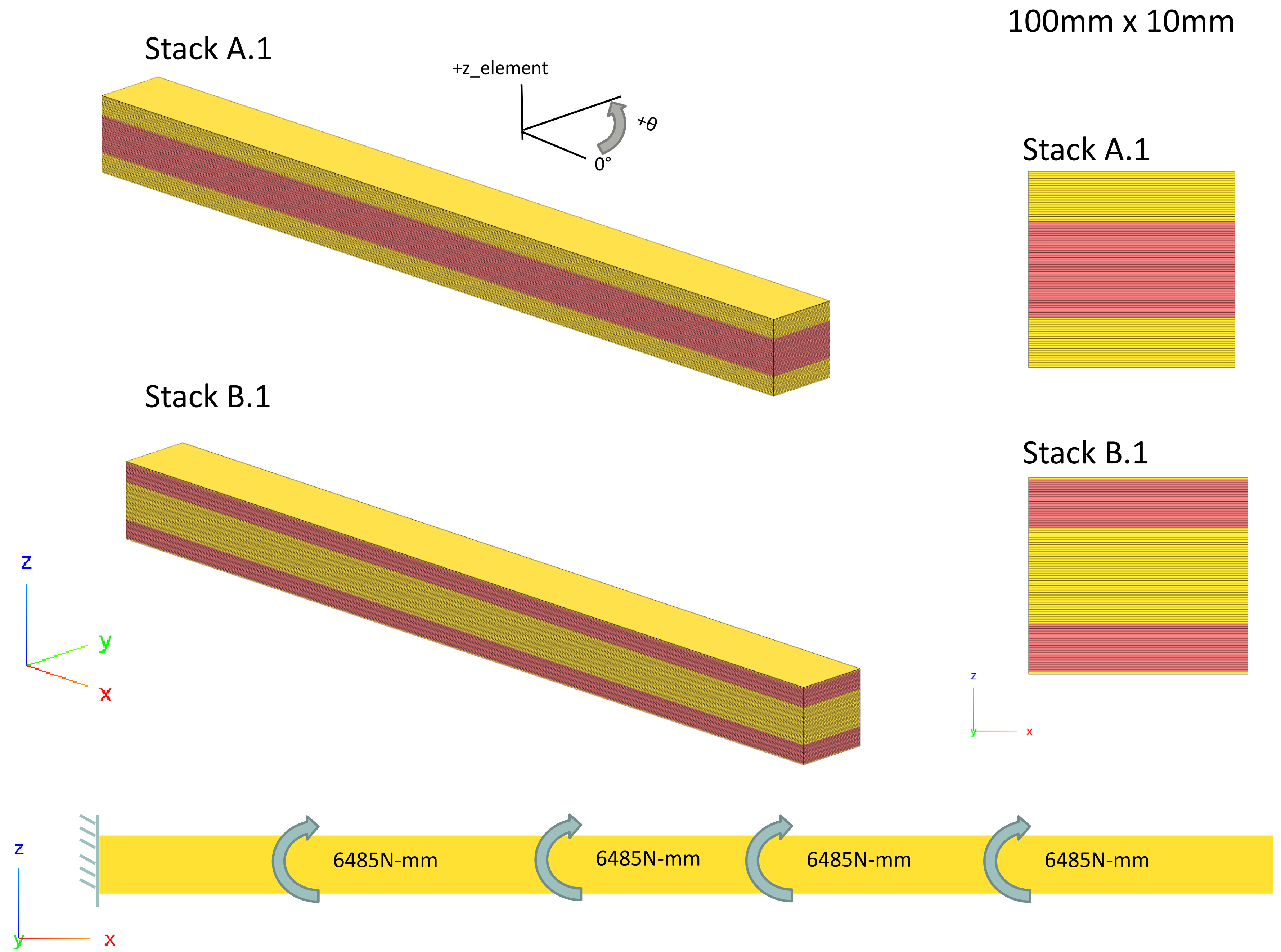
The number of 0° and 90° plies will be optimized to minimize weight and satisfy failure index (Hill) constraints. An optimized composite will have a different number of 0° and 90° plies, but will make discussion difficult. To simplify this discussion, the optimization is performed by requiring an equal number of 0° and 90° plies.

The plies are .125mm thick. The starting stack has 82 plies.

One 0° ply is placed on the top and bottom of the stack and will be used to track the maximum failure index. The 0° ply on the top and bottom will remain at the top and bottom during this optimization procedure.

The only difference between stacks A.1 and B.1 is that in stack A.1 the 0° plies are the outermost plies but in stack B.1 the 0° plies are the innermost plies.

The question going forward is: why optimize [90/0] (stack B.1) instead of [0/90] (A.1)?



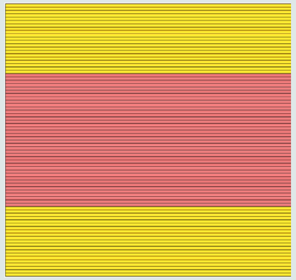
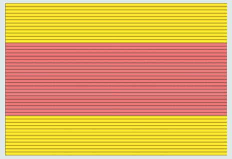
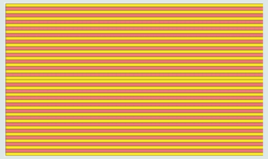
Comparison of Optimizing Stacks A.1 and B.1

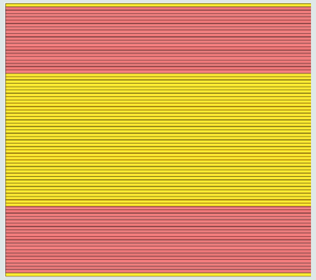
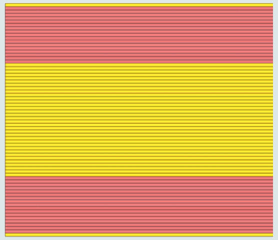
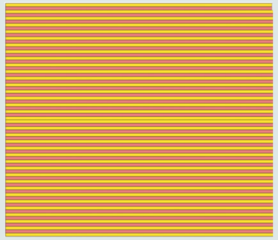
A ply number optimization is performed for stacks A.1 and B.1, which yields new stacks A.2 and B.2, respectively. Then a separate stacking sequence optimization is performed on stacks A.2 and B.2 to yield new stacks A.3. and B.3, respectively.

Observe how stacks A.1 and A.2 are feasible, but stack A.3 is infeasible, since 1.0 < 1.4698. The stacking sequence optimization has made the stack infeasible.

Stacks B.1, B.2 and B.3 are feasible. The stacking sequence optimization has modified the stiffness of the composite but the failure index remains satisfactory, since 0.7887 < 1.0.

Since a ply number optimization and stacking sequence optimization are performed separately, there is a risk that feasible designs become infeasible after stacking sequence optimization. Whether or not a feasible design is obtained after a stacking sequence optimization is dependent on the initial stacking sequence of the PCOMP entry.

Stack	A.1	A.2	A.3
Comments	Starting Stack	After Ply Number Optimization	After Stacking Sequence Optimization
	Number of 0° plies: 40 Number of 90° plies: 40	Number of 0° plies: 22 Number of 90° plies: 22	Number of 0° plies: 22 Number of 90° plies: 22
Max Failure Index	0.0703	0.6880	1.4698
D11	31.9E+05	5.67E+05	3.93E+05
			

Stack	B.1	B.2	B.3
Comments	Starting Stack	After Ply Number Optimization	After Stacking Sequence Optimization
	Number of 0° plies: 40 Number of 90° plies: 40	Number of 0° plies: 34 Number of 90° plies: 34	Number of 0° plies: 34 Number of 90° plies: 34
Max Failure Index	0.4624	0.8287	0.2863
D11	12.7E+05	8.08E+05	13.6E+05
			

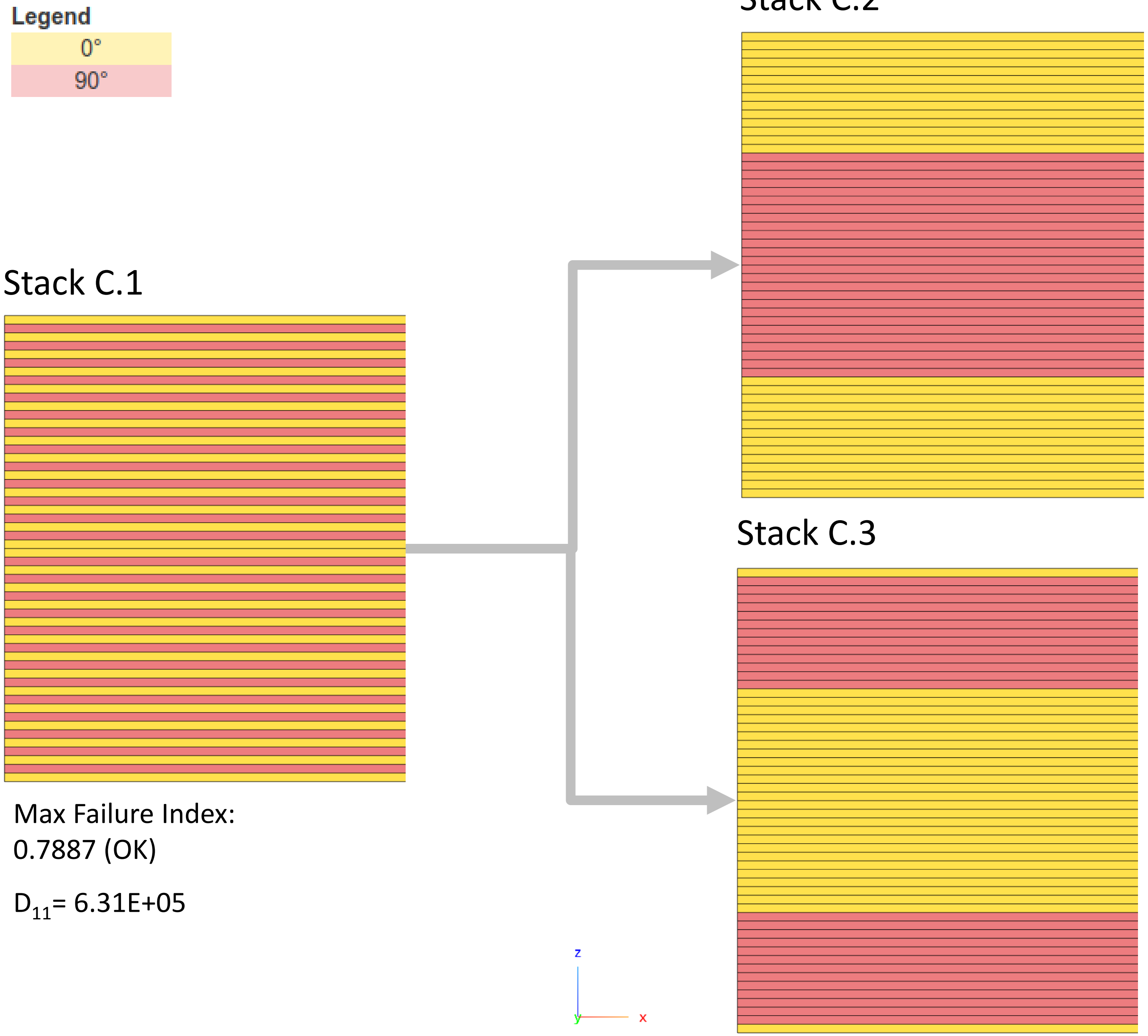
Finite Number of Possible Stacking Sequences

Suppose you have a stack with a fixed number of plies. There is a finite number of sequences the plies may be arranged. When generating different stacking sequences, there is a maximum and minimum stiffness that may be obtained.

For the example shown, stack C.1 is rearranged to produce 2 different stacking sequences C.2 and C.3. The maximum stiffness obtainable is produced by stack C.2. The minimum stiffness obtainable is produced by stack C.3.

Notice the maximum failure index varies depending on the stacking sequence. Stack C.3 yields a maximum failure index that is significantly greater than the allowable value of 1.0. Stack C.3 is infeasible while stacks C.1 and C2. are feasible.

For a fixed number of plies, a stacking sequence optimization may reduce the stiffness, which could cause the constraints on responses to be violated.



Stack C.1: Max Failure Index: 0.7887 (OK)

D_{11}= 6.31E+05

Stack C.2: Max Failure Index: 0.3661 (OK)

D_{11}= 9.16E+05

Stack C.3: Max Failure Index: 2.1256 (NOT OK)

D_{11}= 3.88E+05

Maximum and Minimum Possible Stiffness Obtainable

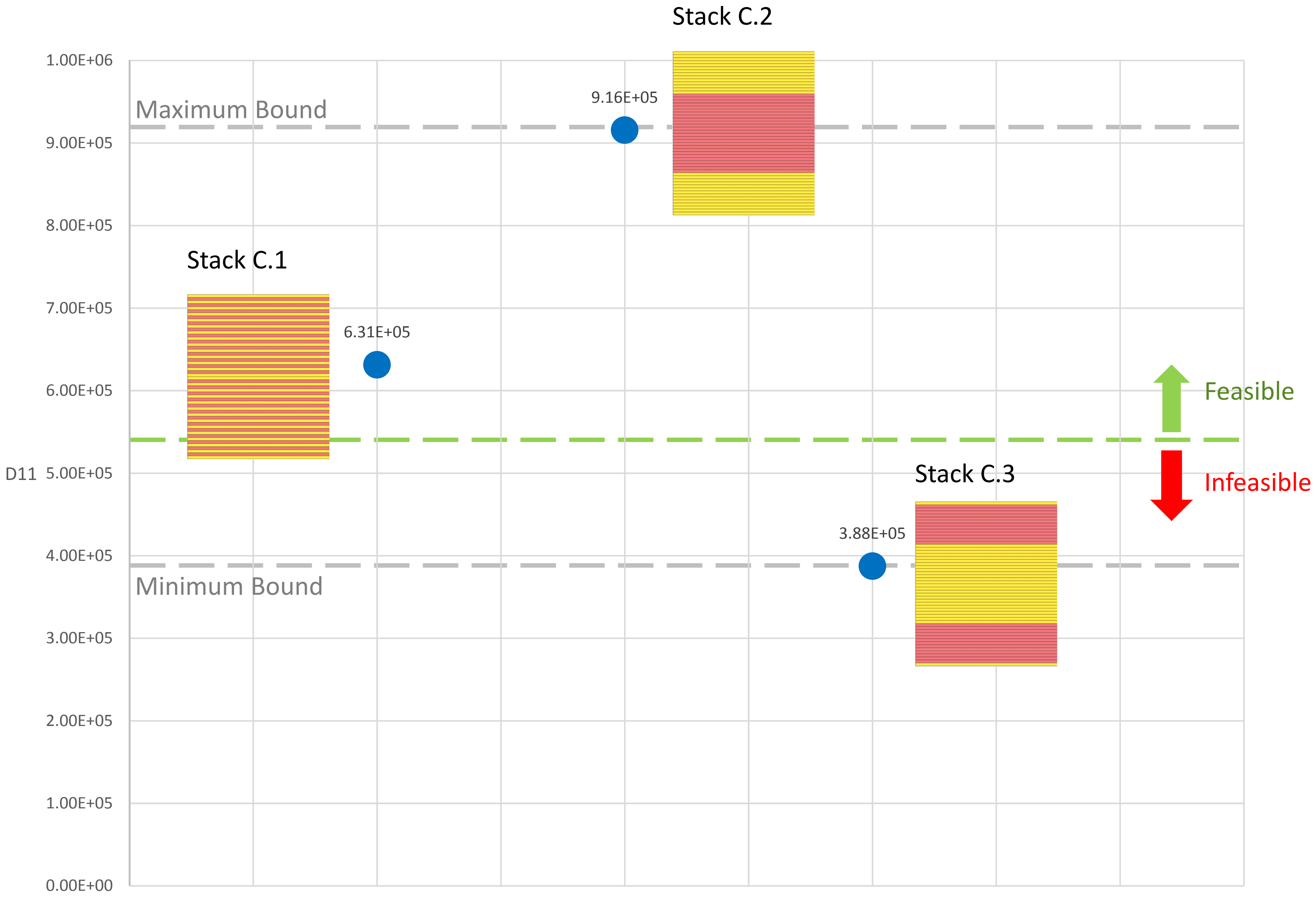
Recall the following.

> *When there are a fixed number of plies, there are a finite number of stacking sequences. Out of all possible stacking sequences, there is maximum bound and a minimum bound on possible stiffness values that may be obtained.*

The diagram to the right displays the maximum and minimum bounds of possible stiffness values obtainable by different stacking sequences of stack C.1.

Also present is a feasible boundary that separates stiffness values that yield feasible designs from stiffness values that yield infeasible designs. The feasible boundary is not immediately known. In the diagram, the feasible boundary is approximately placed.

Consider stack C.3. When the 90° plies are placed as the outermost plies, the stack tends to yield a stiffness on or close to the minimum bound on possible stiffness values. This will be very important later on in the discussion.



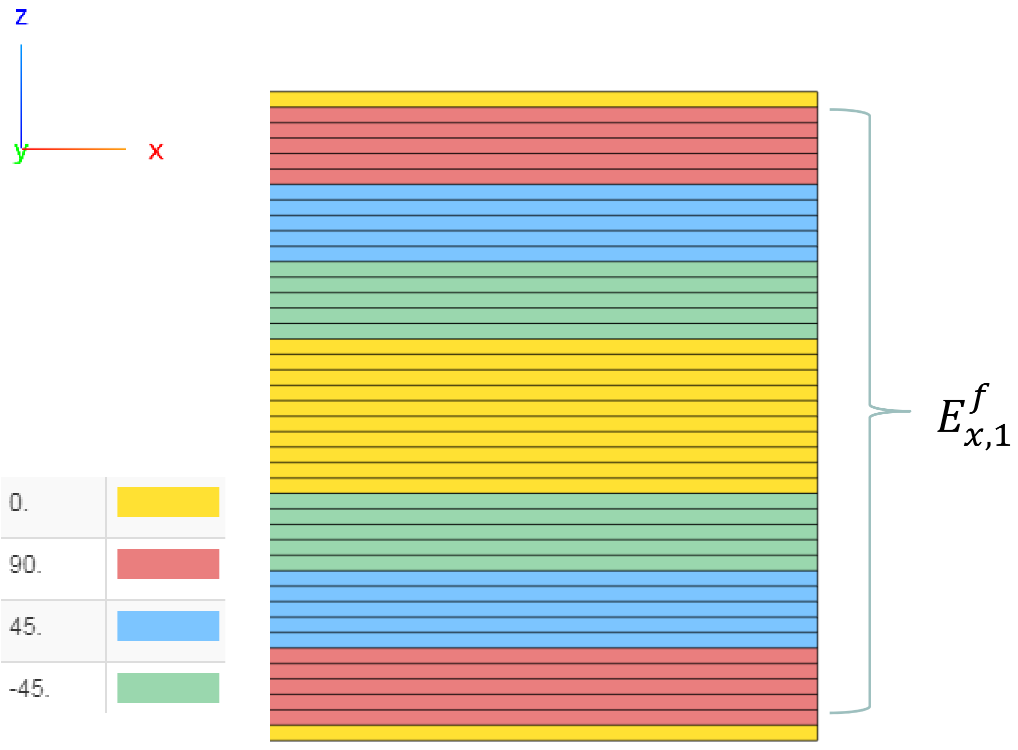
Unknown Final Stiffness After Stacking Sequence Optimization

The ply number optimization is done separate from the stacking sequence optimization. The ply number optimization yields a feasible design assuming the stacking sequence remains fixed, but as demonstrated, a subsequent stacking sequence optimization will change the stiffness. After a stacking sequence optimization, the change in stiffness is what sometimes makes a feasible design infeasible.

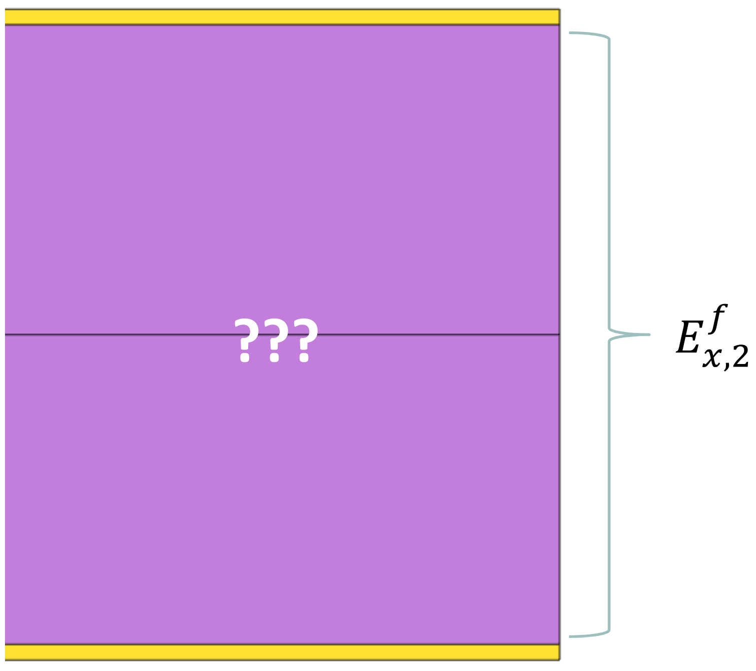
The final stiffness of the laminate is effectively unknown during the ply number optimization.

A strategy is proposed to help ensure the final stacking sequence is feasible.

1: Stack after ply number optimization
2: Stack after stacking sequence optimization



Stack after ply shape and ply number optimization



Unknown Future Stack after Stacking Sequence Optimization

Effective flexural longitudinal modulus

$$E^f_x \equiv \frac{12}{h^3\, D^*_{11}}$$

$$[D^*] = [D]^{-1}$$

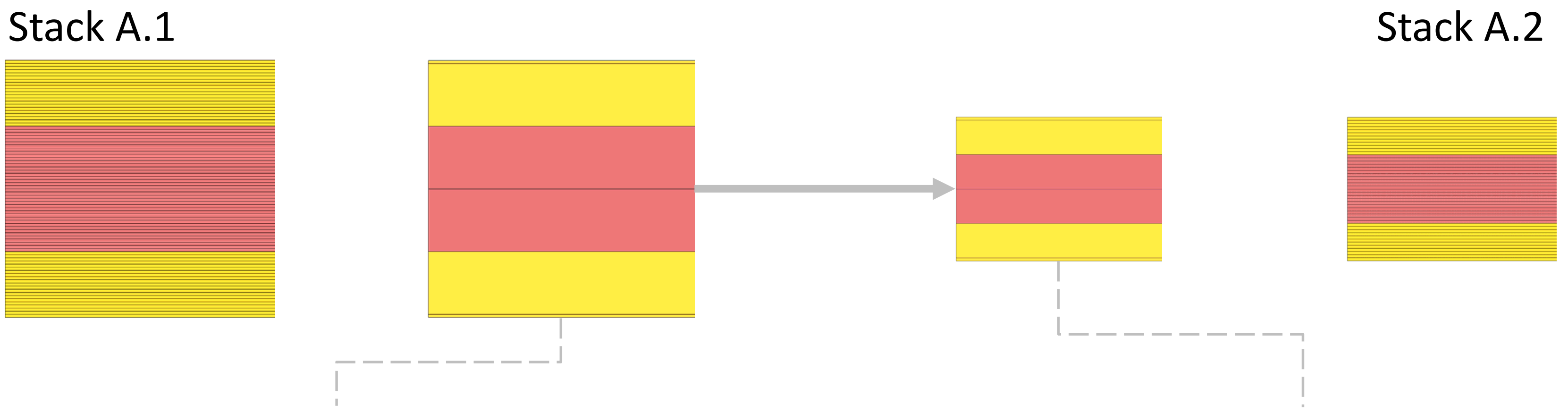
The final stiffness ($E^f_{x,2}$) of the stack after stacking sequence optimization is unknown during ply number optimization

Strategy: Place the 0° layers as the innermost layers and 90° layers as the outermost layers

Recall stack C.3 from before, which yielded a stack with the smallest possible stiffness. Stack C.3 has the 90° plies as the outermost plies.

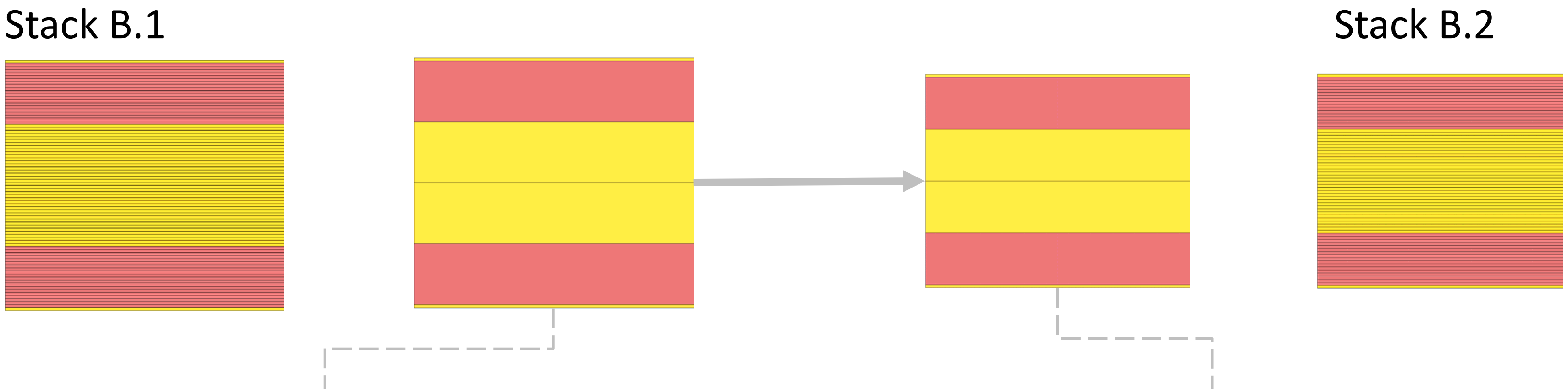
During ply number optimization, it is recommended that the PCOMP entry have the 90° super-ply layers furthest from the midplane, as done in stack B.1. This helps ensure the new stack after ply number optimization and stacking sequence optimization is feasible.

A ply number optimization is achieved by optimizing the thickness of super-ply layers defined on the PCOMP entry, then separating the super-ply layer into an equivalent number of plies. For example. For stack B.2, the optimized thickness of the 90° super-ply layer is 2.125. Since each ply has a thickness of 0.125, a super-ply layer thickness of 2.125 is equivalent to 17 plies. Since LAM=SYM, there is a total of thirty four (34) 90° plies in stack B.2.




```
PCOMP,1,,,90.,,,,,SYM
          101      .125     0.       YES
          101      2.5      0.       YES
          101      2.5      90.      YES
```

```
PCOMP,1,,,90.,,,,,SYM
          101 .125       0.0        YES
          101 1.375      0.0        YES
          101 1.375    90.          YES
```




```
PCOMP,1,,,90.,,,,,SYM
          101      .125     0.       YES
          101      2.5      90.      YES
          101      2.5      0.       YES
```

```
PCOMP,1,,,90.,,,,,SYM
          101 .125       0.0        YES
          101 2.125    90.          YES
          101 2.125      0.0        YES
```

Strategy: Place the 0° layers as the innermost layers and 90° layers as the outermost layers

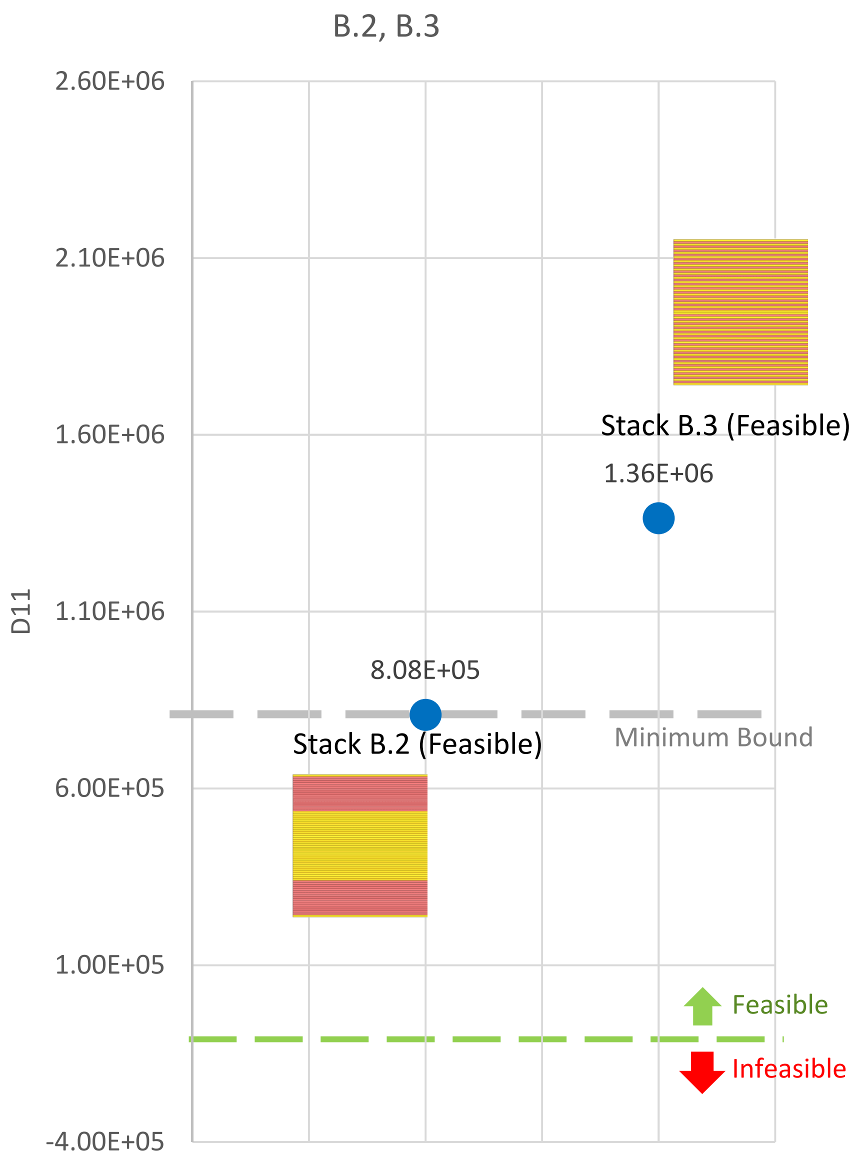
Recall that for a finite number of plies, there are a finite number of stacking sequences possible, and there exists a maximum and minimum bound to possible stiffness values.

Stack A.1 has 0° plies as the outermost plies. This yielded stack A.2 after a ply number optimization. Stack A.2 is on the maximum bound of possible stiffness values. For a fixed number of plies, any stacking sequence optimization will reduce the stiffness. If the stiffness is reduced enough, an infeasible design is produced.

Stack B.1 has 0° plies as the innermost plies. This yielded stack B.2 after a ply number optimization. Stack B.2 is on the minimum bound of possible stiffness values. For a fixed number of plies, any stacking sequence optimization will increase the stiffness.

The displayed feasible boundaries are approximate. Note that for stack B.2, no stacking sequence will breach the feasible boundary. For a fixed number of plies, any stacking sequence will always yield a feasible design.

Starting the ply number optimization where the 0° super-ply layers are the inner most layers yields a stack that is more likely to satisfy constraints after stacking sequence optimization.



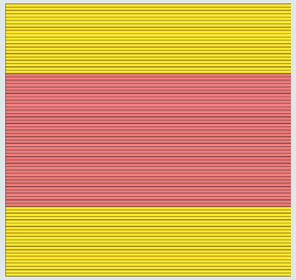
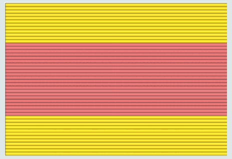
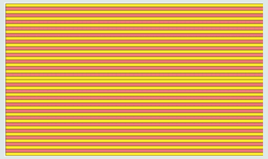
How to improve the composite?

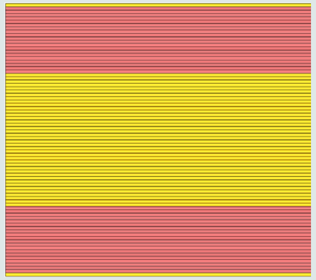
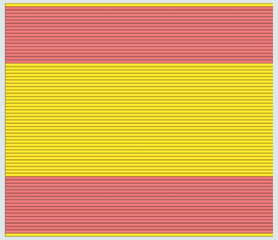
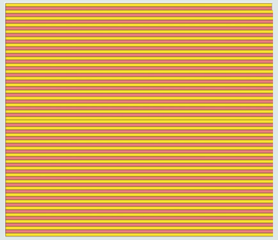
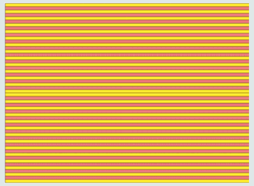
It might be reasoned that performing a ply number optimization where the 0° plies are the innermost plies will produce a significantly conservative composite, such as stacks B.2 and B.3. Stack B.3's maximum failure index is .2863 which is well under the upper limit of 1.0. Stack B.3 could still be optimized to yield greater mass savings.

An additional ply thickness optimization is performed to identify plies that are negligible. Then negligible plies are manually removed from the PCOMP entry. This was done and a new stack B.4 was produced. Stack B.4 features fewer plies and its maximum failure index of 0.7887 is less than 1.0.

Conclusion:

- Place the 0° super-ply layers as the innermost layers and 90° supper-ply layers as the outermost layers and perform the ply number optimization in this configuration. Following this suggestion yielded feasible designs B.2, B.3 and B.4. Not following this suggestion could lead to infeasible designs such as stack A.3.

Stack	A.1	A.2	A.3
Comments	Starting Stack	After Ply Number Optimization	After Stacking Sequence Optimization
	Number of 0° plies: 40 Number of 90° plies: 40	Number of 0° plies: 22 Number of 90° plies: 22	Number of 0° plies: 22 Number of 90° plies: 22
Max Failure Index	0.0703	0.6880	1.4698
D11	31.9E+05	5.67E+05	3.93E+05
			

Stack	B.1	B.2	B.3	B.4
Comments	Starting Stack	After Ply Number Optimization	After Stacking Sequence Optimization	After Another Ply Thickness Optimization to Eliminate Unnecessary Plies
	Number of 0° plies: 40 Number of 90° plies: 40	Number of 0° plies: 34 Number of 90° plies: 34	Number of 0° plies: 34 Number of 90° plies: 34	Number of 0° plies: 26 Number of 90° plies: 26
Max Failure Index	0.4624	0.8287	0.2863	0.7887
D11	12.7E+05	8.08E+05	13.6E+05	6.31E+05
				

Determination of D_{11}

When a PCOMP entry is defined, a corresponding set of PSHELL and MAT2 entries are created and used internally by MSC Nastran.

When these entries or statements are used in the BDF file,

1. NASTRAN SYSTEM(361)=1
2. ECHO=SORT(PCOMP) or ECHO=SORT

the F06 file has the equivalent PSHELL and MAT2 entries.

The thickness (5.25mm) from the PSHELL entry and the G11, G12, etc. values on the MAT2 entries are used to determine A and D. Since the composite is symmetric, [B] has zeros.

Equivalent PSHELL and MAT2 entries

```
*** USER INFORMATION MESSAGE 4379 (IFP6CS)
     THE USER SUPPLIED PCOMP BULK DATA CARDS ARE REPLACED BY THE FOLLOWING PSHELL AND MAT2 CARDS.
     WARNING, MAT2 RECORDS WITH MID GREATER THAN 400000000 USE A SPECIAL FORMAT FOR PCOMPS.
     REFER TO REMARK 13 OF THE MAT2 DESCRIPTION IN THE MSC NASTRAN QUICK REFERENCE GUIDE.
 PSHELL            1     10000001  5.2500E+00    10000002  1.0000E+00           0  1.0000E+00  0.0000E+00
          -2.6250E+00  2.6250E+00           0
  MAT2       10000001  2.4512E+04  2.1818E+03  2.9251E-10  2.3047E+04  4.0558E-09  4.1400E+03  1.6650E-09
           1.1168E+01  1.1540E+01 -5.9230E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
                    0  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  MAT2       10000002  1.5905E+04  2.1818E+03  4.6430E-10  3.1654E+04  6.4379E-09  4.1400E+03  1.6650E-09
           1.4273E+01  9.7861E+00 -7.0220E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
                    0  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
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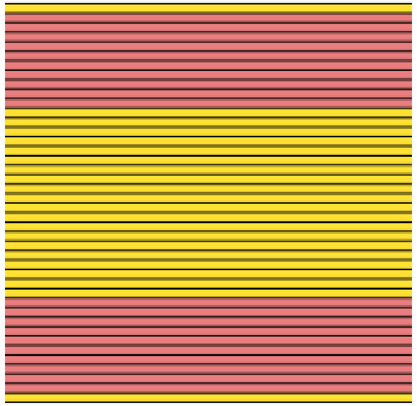

$$[A] = \begin{bmatrix} 2.4512E+04 & 2.1818E+03 & 2.9251E-10 \\ SYM & 2.3047E+04 & 4.0558E-09 \\ SYM & SYM & 4.1400E+03 \end{bmatrix} 5.25$$

$$= \begin{bmatrix} 1.29E+05 & 1.15E+04 & \sim 0 \\ SYM & 1.21E+05 & \sim 0 \\ SYM & SYM & 2.17E+04 \end{bmatrix}$$

$$[D] = \begin{bmatrix} 1.5905E+04 & 2.1818E+03 & 4.6430E-10 \\ SYM & 3.1654E+04 & 6.4379E-09 \\ SYM & SYM & 4.1400E+03 \end{bmatrix} \frac{5.25^3}{12}$$

$$= \begin{bmatrix} 1.92E+05 & 2.63E+04 & \sim 0 \\ SYM & 3.82E+05 & \sim 0 \\ SYM & SYM & 4.99E+04 \end{bmatrix}$$

D_{11} = 1.92E+05

Why is the ply number optimization configured to start with 1 ply instead of the original 5 plies?

Why is the ply number optimization configured to start with 1 ply instead of the original 5 plies?

Composite ply number or ply thickness optimization has numerous solutions. The path the optimizer takes towards an optimum is dependent on the following factors: starting point (initial design), move limits, smoothness of the response surfaces, and proximity to a local optimum.

The ply number optimization from this workshop is repeated with ply number variables y1 (0°) and y2 (90°). Consider two optimizations with different initial values for the ply number variables.

- Optimization A: y1 and y2 have an initial value of 50 plies
- Optimization B: y1 and y2 have an initial value of 1 ply

It is generally best practice to start the optimization with a feasible design. This is ensured by setting the initial variable values to large values, as done in optimization A. This best practice does not apply to ply number or ply thickness optimization.

Observe how the optimizer arrives at different local optimums. Optimization A yields 6 plies and optimization B yields 5 plies. Optimization B yields the best optimal solution, i.e. fewer plies means less mass. By purposely setting the initial variables to small values the optimizer starts the optimization relatively close to a likely global solution.