Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization

AN MSC NASTRAN SOL 200 TUTORIAL

Composite Workshop

This workshop is phase E 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

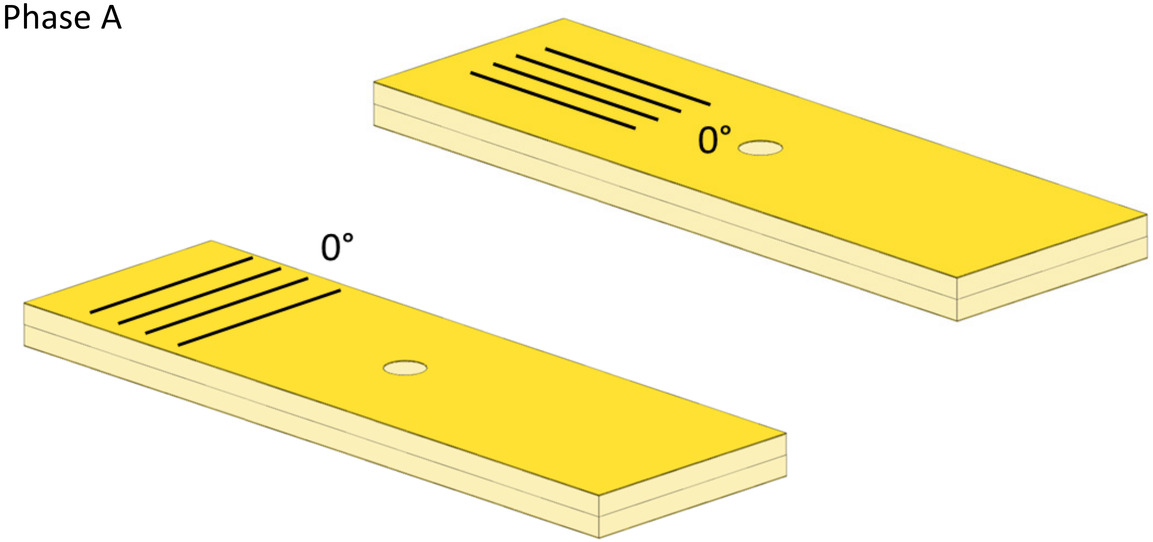
- Perform a ply number optimization with full and continuous ply shapes
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

0° Direction Optimization → Baseline Ply Number Optimization

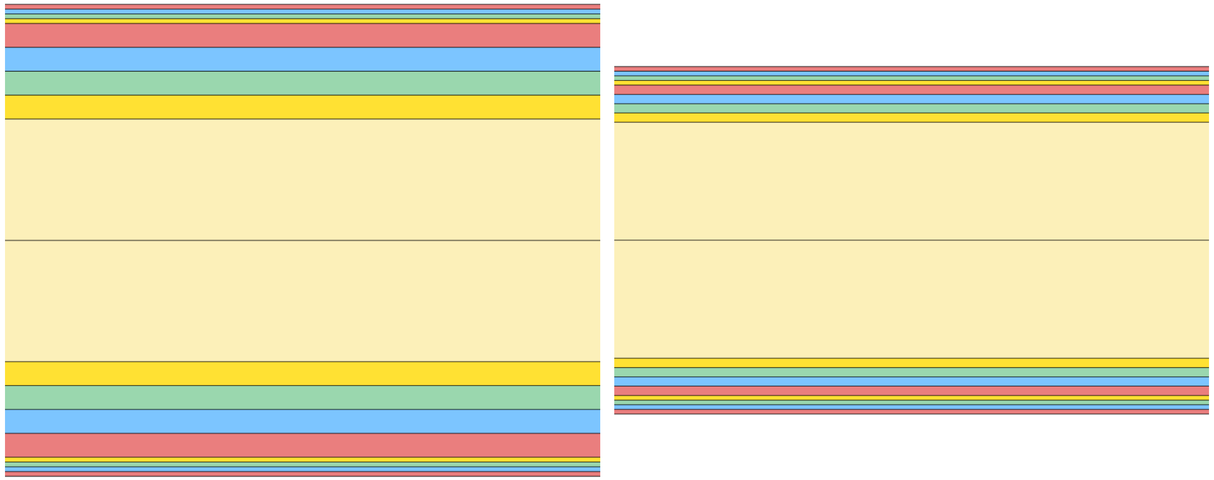
Composite Workshop

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

Phase A



Phase B



0° Direction Optimization

Baseline Ply Number Optimization

Composite Workshop

This workshop is phase E 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

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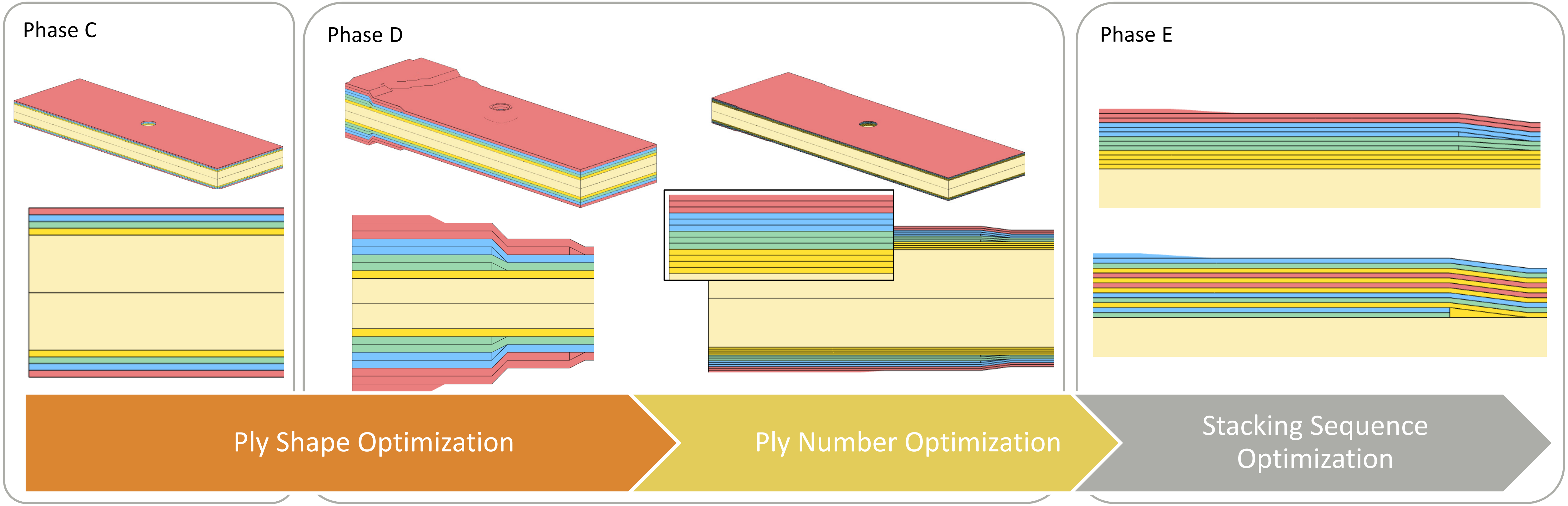
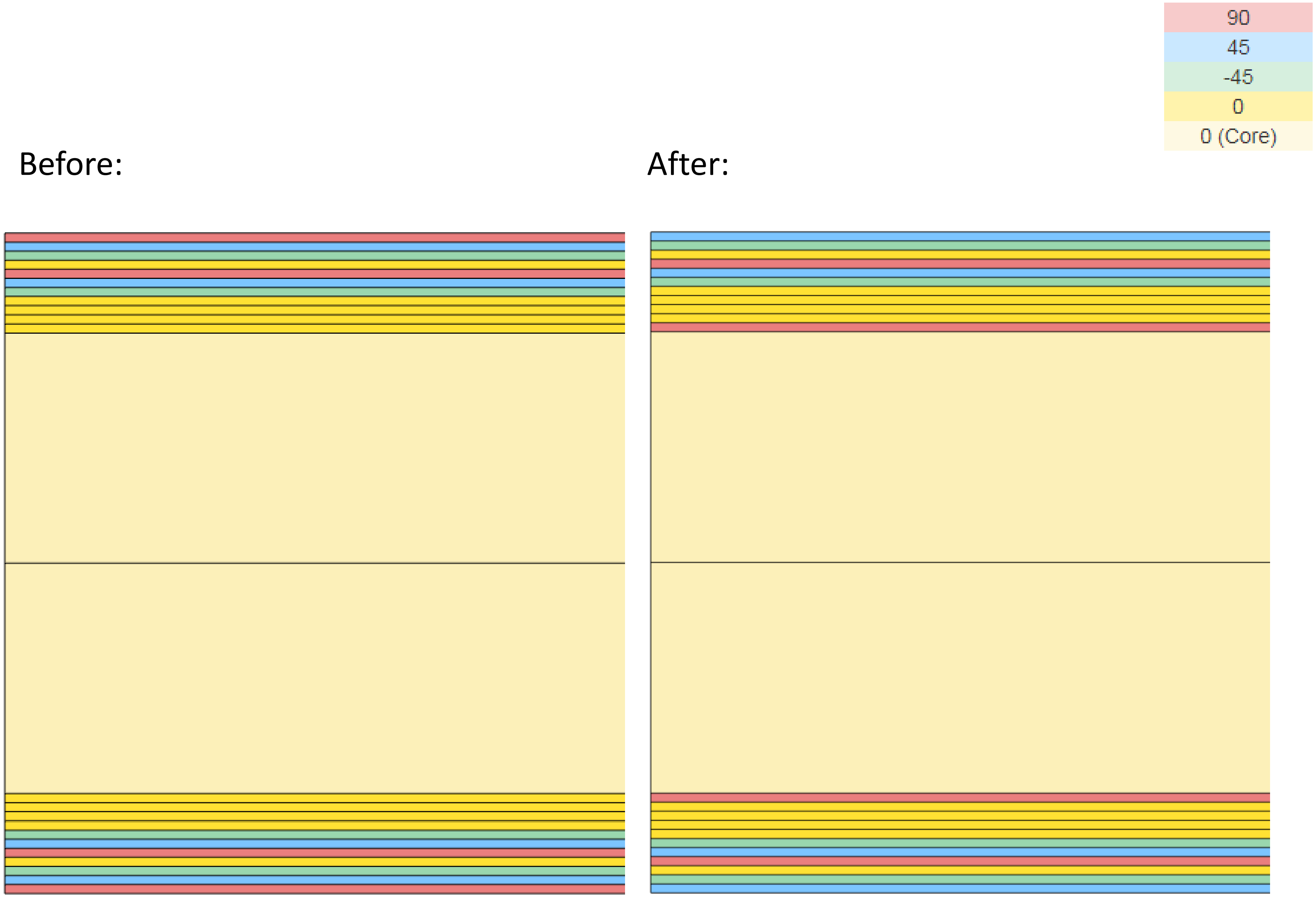
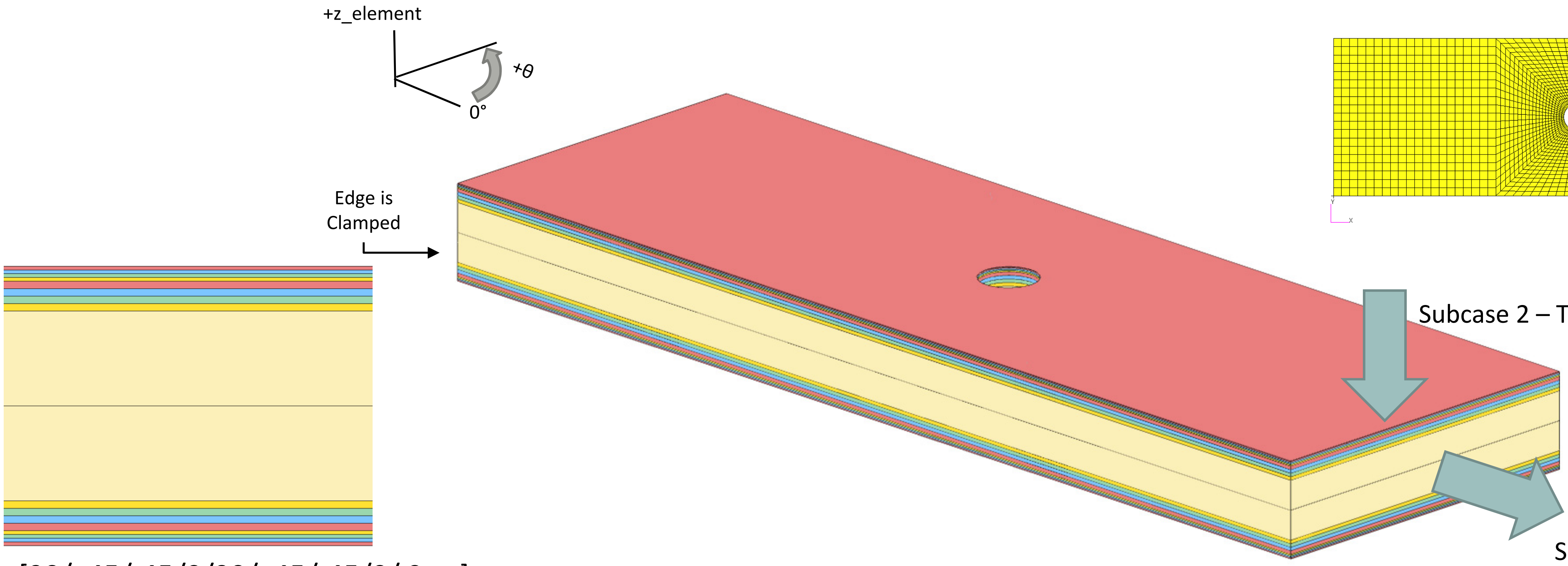


Goal: Perform a Stacking Sequence Optimization

- The goal is to construct ply shapes that produce a lightweight composite but satisfy failure index constraints.
- This tutorial discusses how perform a stacking sequence optimization.

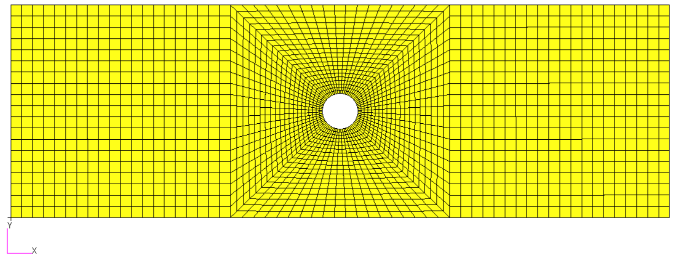


Details of the structural model



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

118mm x 38.1mm
Radius: 3.175mm

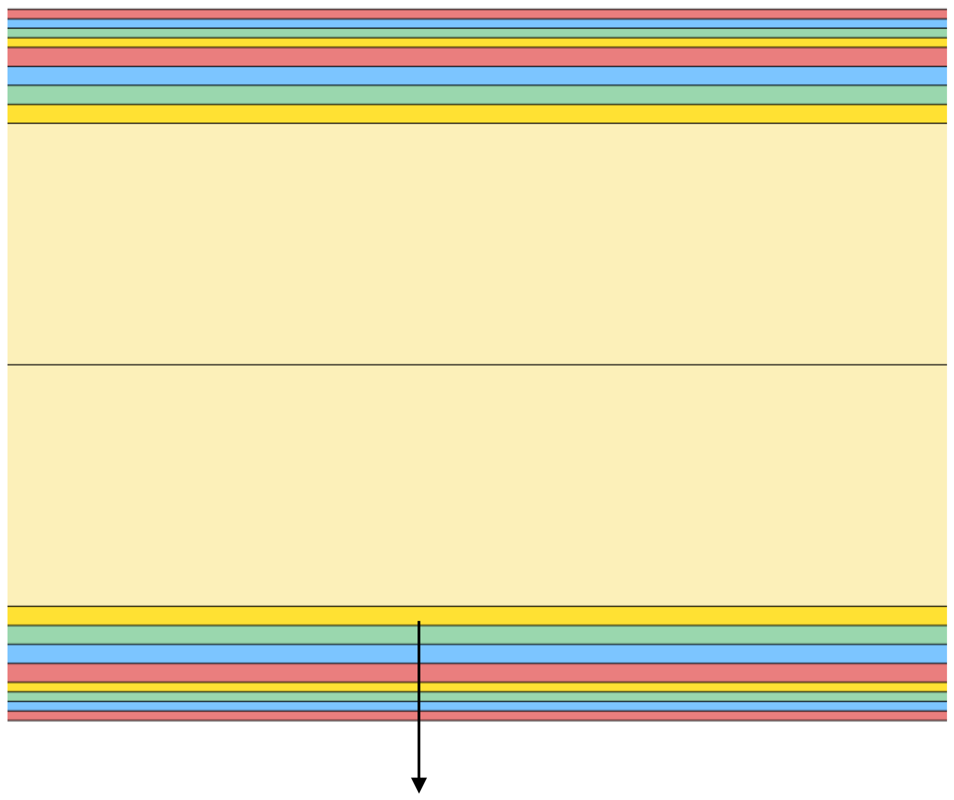


Details of the Composite Layers

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.

- 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.



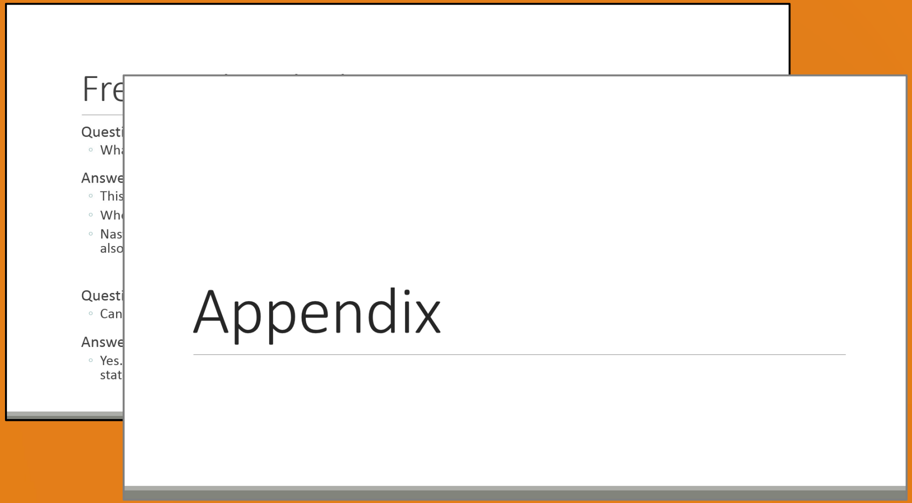
45°	blue
-45°	green
90°	red
0°	yellow
0° (Core)	light yellow

```
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     .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
```

More Information Available in the Appendix

The Appendix includes information regarding the following:

- Options - Stacking Sequence Optimization



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

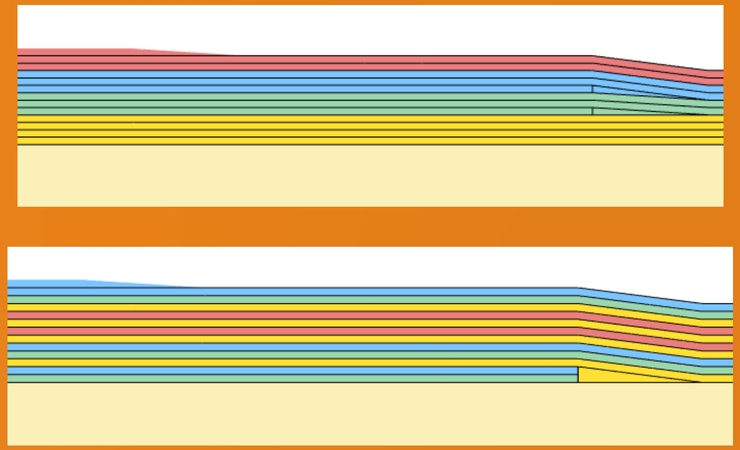
Tutorial

Tutorial Overview

1. Input BDF
2. Perform Stacking Sequence Optimization
3. Validate Performance
4. Inspect Plies

Special Topics Covered

Manufacturing Constraints - 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.



SOL 200 Web App Capabilities

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

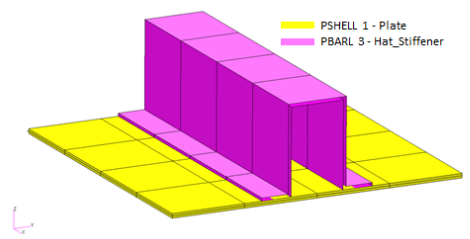
Compatibility

- 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.

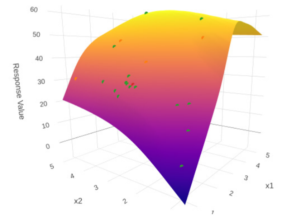
Benefits

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

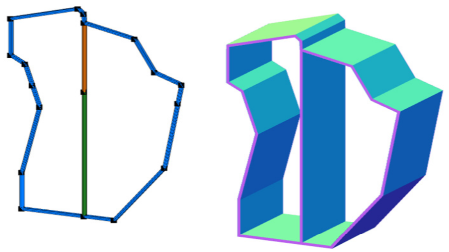
Web Apps



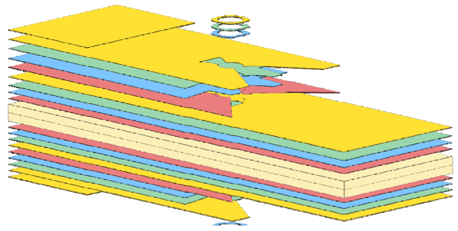
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



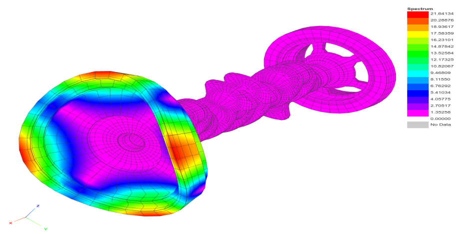
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



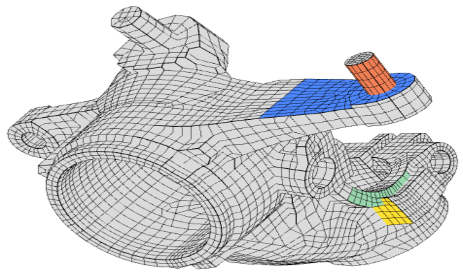
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



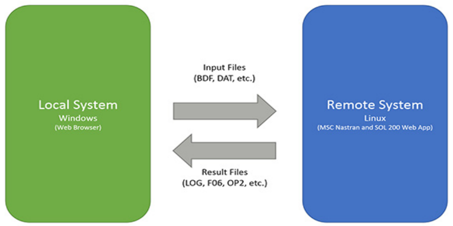
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



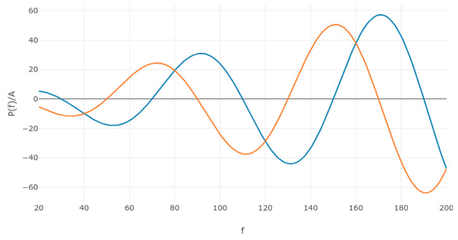
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



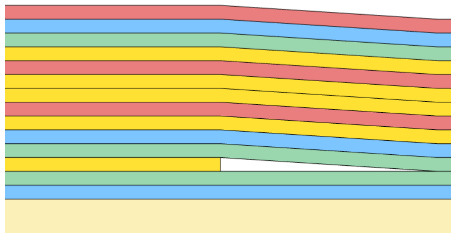
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



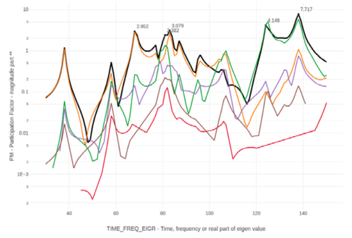
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



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



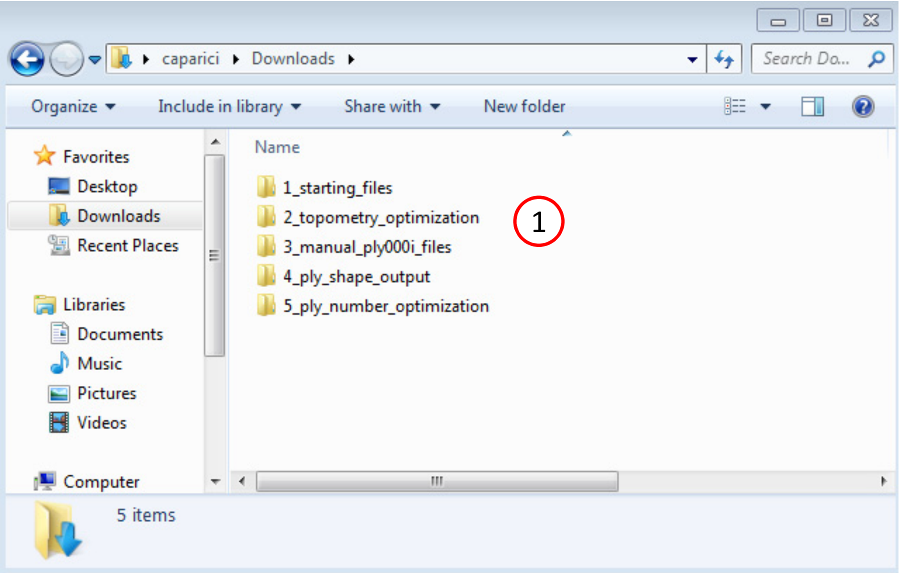
HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

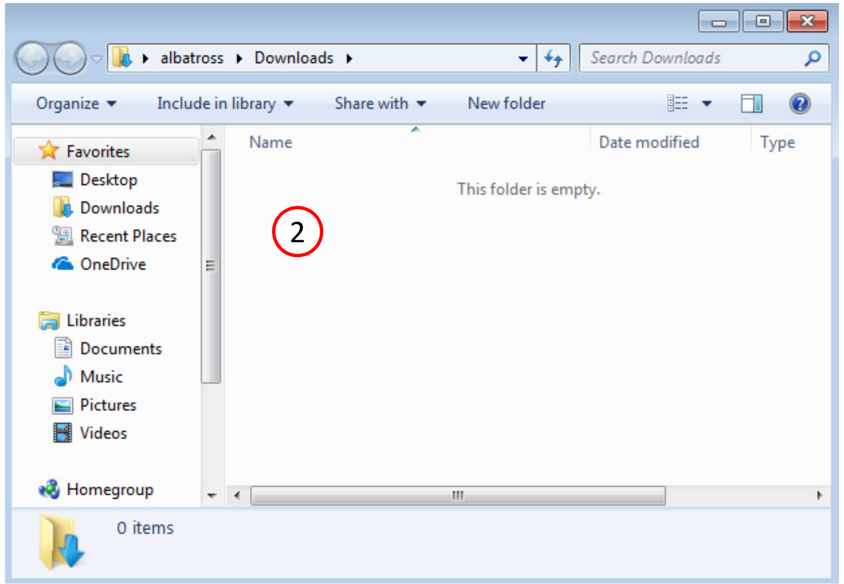
Before Starting

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.

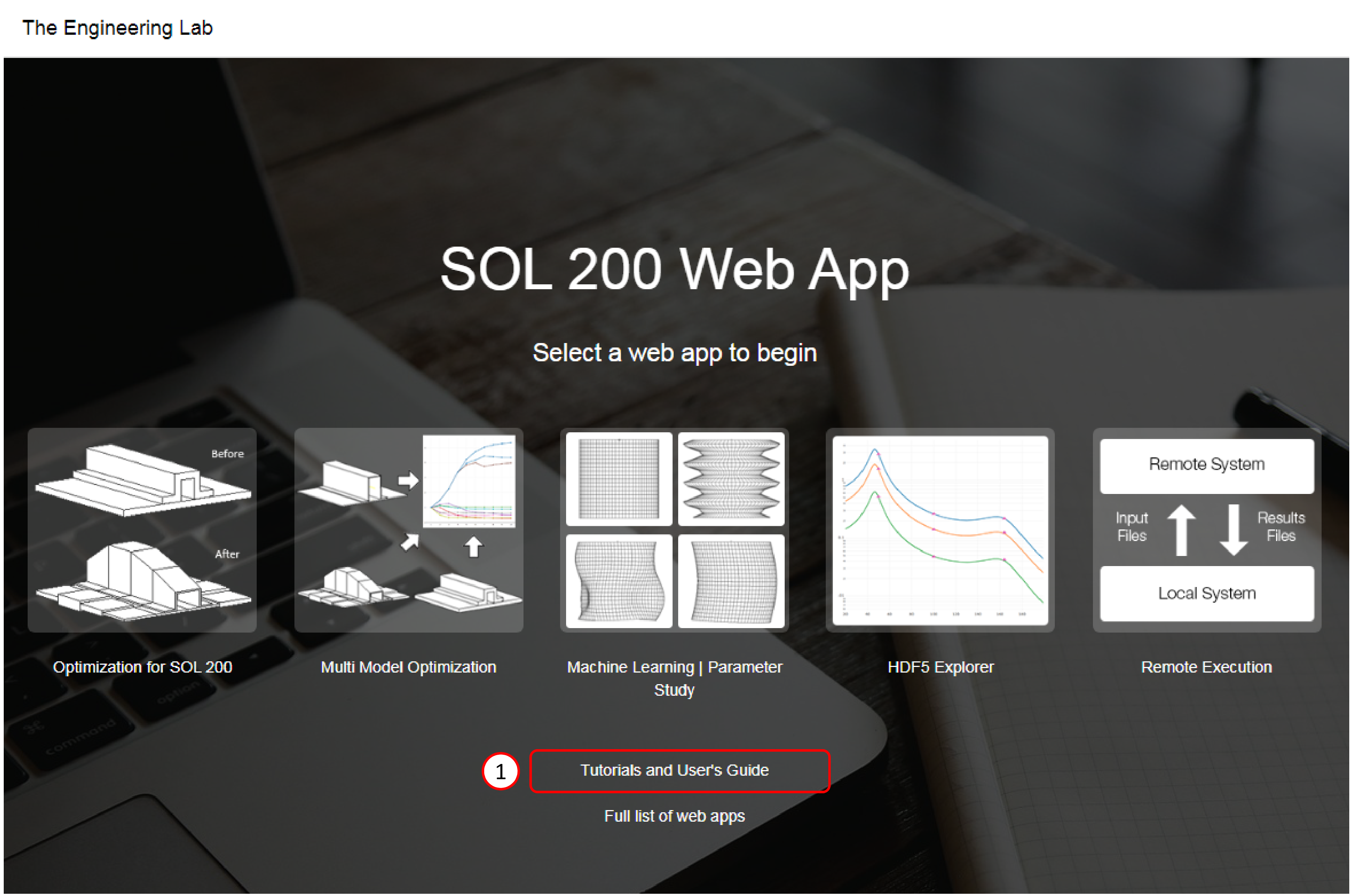




Go to the User's Guide

1. Click on the indicated link

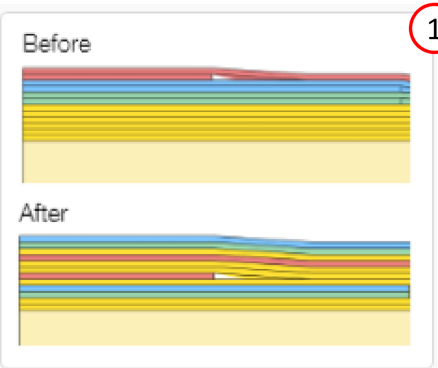
- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.



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.

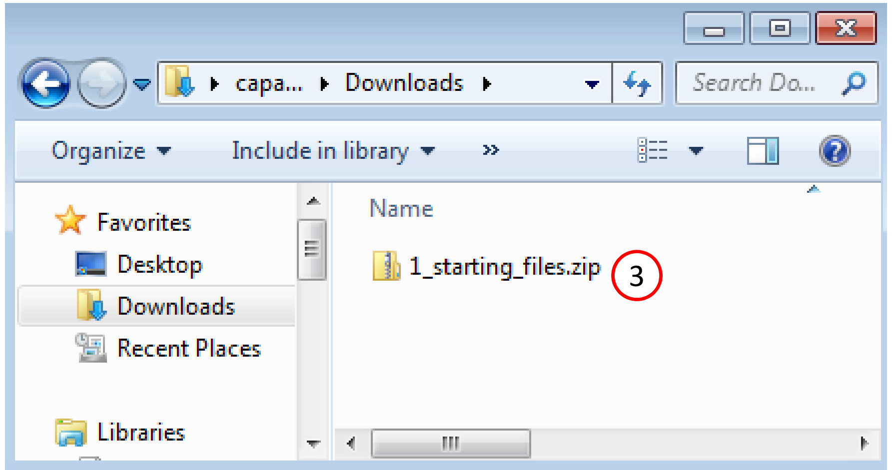


(1) **Composite Coupon – Phase E – Stacking Sequence Optimization**

This tutorial involves performing a stacking sequence optimization and is a continuation of the previous tutorial, phase D. A final statics analysis is performed to confirm the optimized composite satisfies failure index constraints.

This is the fifth phase in a 5-phase tutorial series.

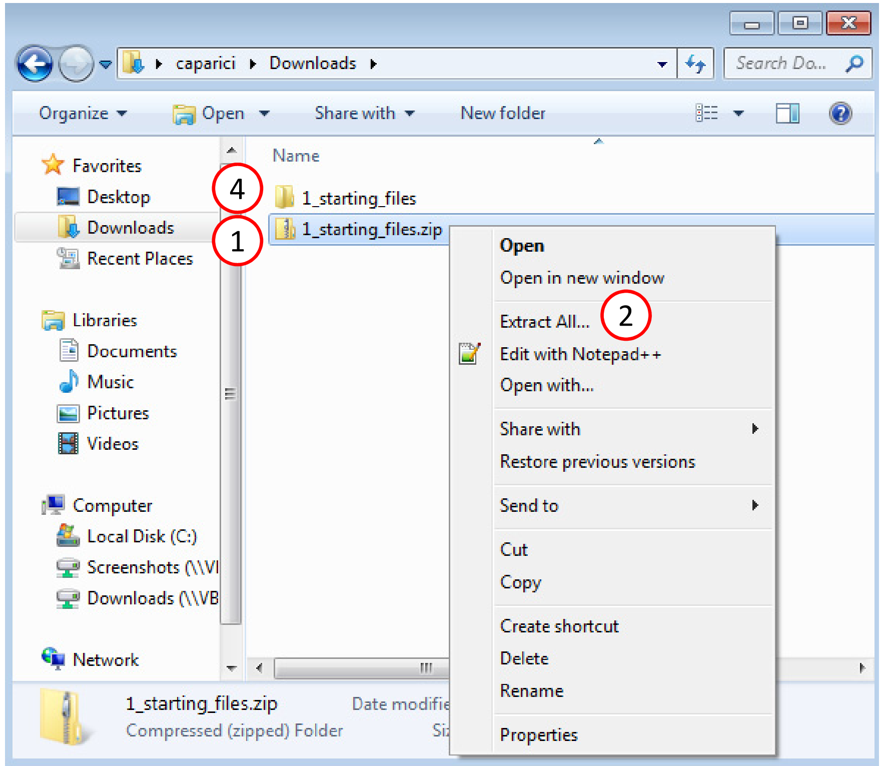
Starting BDF Files: Link (2)
Solution BDF Files: Link

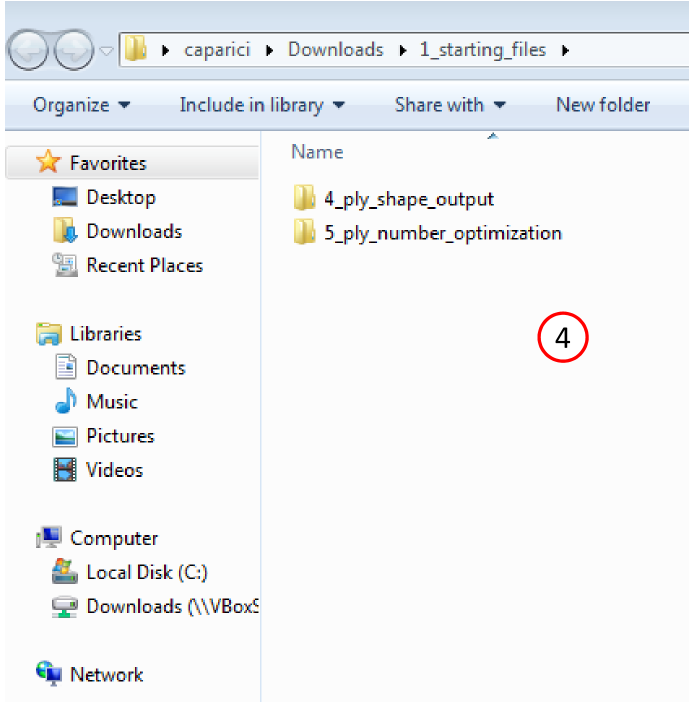


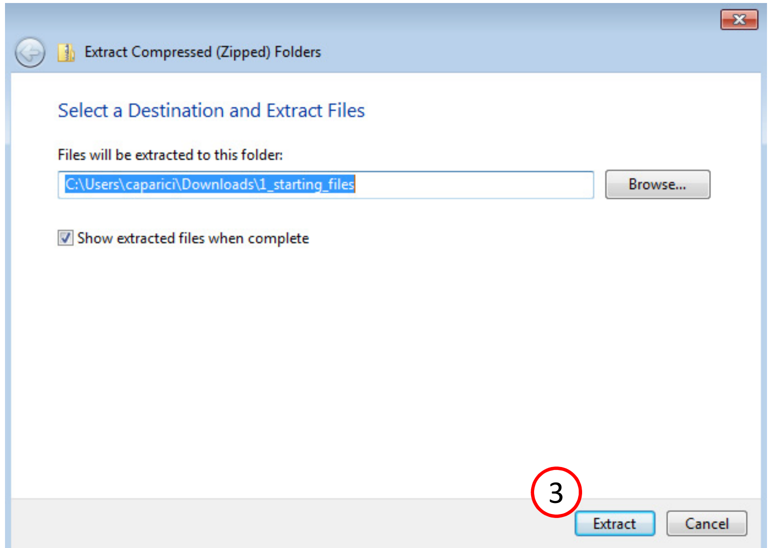
Obtain Starting Files

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

- 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.



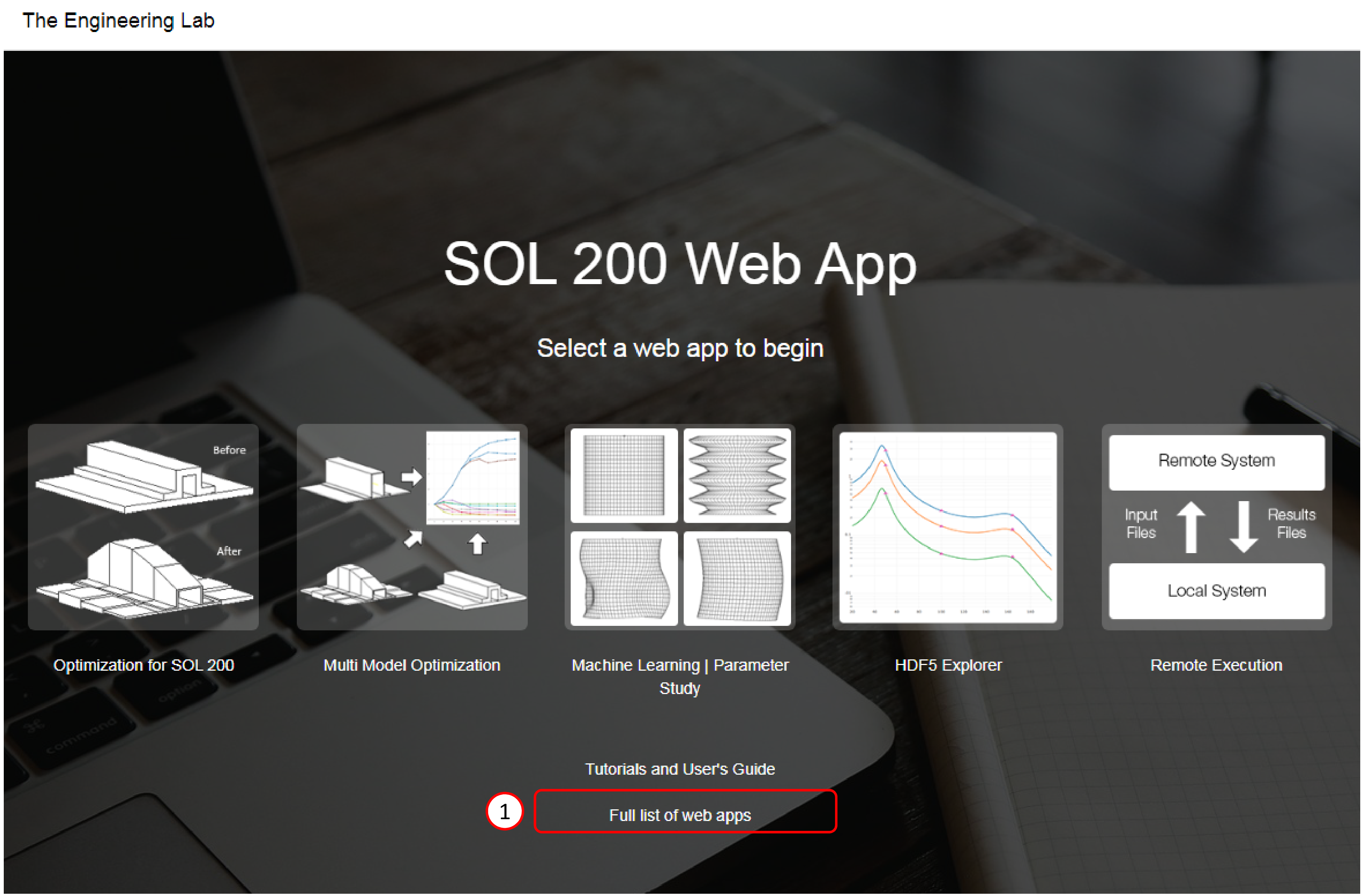




Open the Correct Page

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 Stacking Sequence Web App

1. Navigate to the Composites section
2. Click Stacking Sequence

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For access, visit

the-engineering-lab.com

or contact

christian@ the-engineering-lab.com

Upload Files

1. Click Select files
2. Navigate to workspace_c
3. Select the indicated files
4. Click Open
5. Click Upload files

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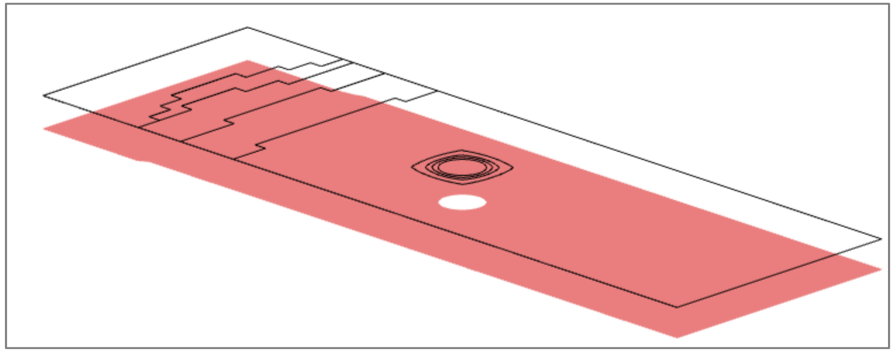
Select a Stack

1. Click Select Stack
2. Select Multiple Stacks
3. Select GPLY 111000

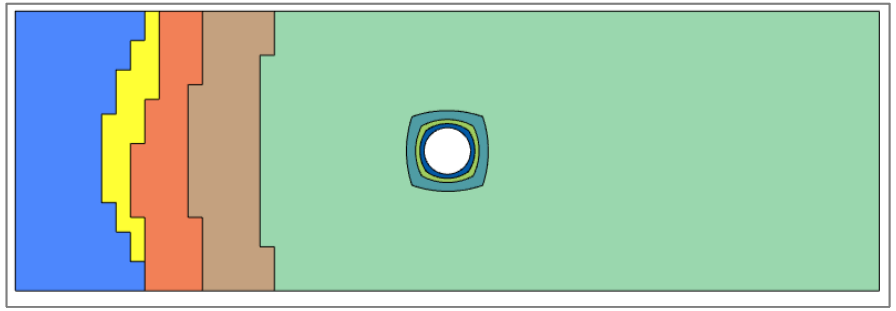
Why is GPLY 111000 selected?

- GPLY 111000 is used by PCOMPG 2-7 and is used by the entire model.
- GPLY 181001 is only used by PCOMPG 3 and covers only a small portion of the model.
- When you select a GPLY, all the associated PCOMPGs are loaded and updated after the stacking sequence optimization. If GPLY 181001 is selected, only PCOMPG 3 is loaded and updated by stacking sequence optimization. Since GPLY 111000 is selected, all PCOMPGs are loaded and updated by the stacking sequence optimization.

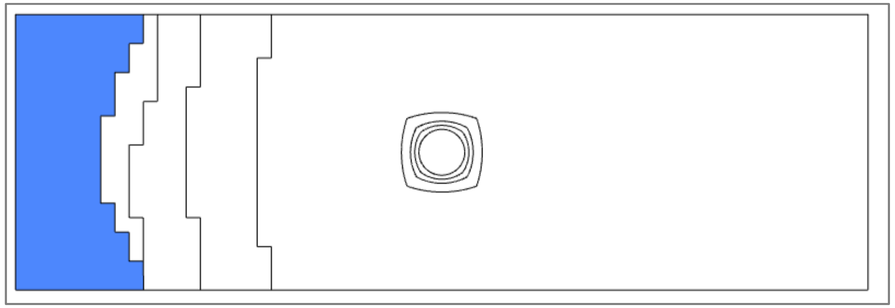
GPLY 111000



PCOMPG 2-9



PCOMPG 3



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Perform Stacking Sequence Optimization

1. Click Optimize

The outermost plies of the composite are to have plies with 45, -45, 0 and 90 degrees.

2. Locate GPLY ID 111000, which is initially in the 1st ply level
3. Find GPLY ID 111000 and click its Down button until the ply is at the ply 4 level
4. Click the indicated buttons. This will fix the plies and these plies will be ignored during the optimization.
5. For the core, GPLY 151000, click the indicated button to fix the core during the optimization.

Fixed plies are not included in the optimization and manufacturing constraints are not considered for fixed plies.

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Perform Stacking Sequence Optimization

1. Click Display Additional Columns. This will display all the PCOMPG entries that will be updated during the stacking sequence optimization.
2. Click Toggle Display of Plies to view how the plies span across each PCOMPG entry.
3. Click Compact Mode.
4. GPLY ID 111000 is shown to span each PCOMPG. This GPLY spans the entire coupon.
5. Notice that the 45-degree and -45-degree plies are not paired. A stacking sequence optimization is performed on the next page to pair the 45-degree plies.

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Perform Stacking Sequence Optimization

1. Click Display Additional Columns
2. Click the indicated buttons. These plies will be temporarily fixed during the optimization.

- The 90° and 0° plies are temporarily fixed. Only the 45° are allowed to vary. Recall that fixed plies are not considered in the optimization. The next slide will consider manufacturing constraints on only the 45° plies.

Perform Stacking Sequence Optimization

1. Scroll to section Configure Manufacturing Constraints
2. Set Pair to YES
3. Click Perform Optimization
4. Navigate to the row labeled Stack Optimized
5. The 45-degree plies are now paired. Note the signs are in the same order, e.g. +45, -45, -45, +45, etc. Some may desire to have the sign alternate, e.g. +45, -45, -45, +45, etc.

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Perform Stacking Sequence Optimization

Repeat the stacking sequence optimization but with an adjustment to the 45-degree pairing

1. Set Pairing Option to REVERSE
2. Click Perform Optimization
3. The 45-degree plies are paired AND are alternating in signs, e.g. +45, -45, -45, +45

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Perform Stacking Sequence Optimization

1. Navigate to the row labeled Stack
2. Click the indicated buttons. These plies will now vary during the optimization.

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Perform Stacking Sequence Optimization

1. Click Perform Optimization
2. Notice that the optimized stack yields 2 adjacent 90-degree plies. This may not be desired in some applications.

- The 90° is fixed. Manufacturing constraints are not considered for fixed plies. There is a manufacturing constraint to prevent adjacent 90° plies, but it will not work in this case since the ply is fixed. To avoid adjacent 90° plies, consider the steps on the next page.

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Perform Stacking Sequence Optimization

1. Navigate to the row labeled Stack
2. Locate GPLY 151001 and click the indicated button until the GPLY is in the 14th position in the stack.
3. Click the indicated button to fix GPLY 151001 during the optimization. Doing this will prevent the 90-degree plies from being adjacent to each other.

- Given the bending in the composite, a 90° near the top does not contribute much to the bending stiffness of the composite. The 90° ply is moved towards the midplane and allows other angles to occupy positions towards the outer plies.

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Perform Stacking Sequence Optimization

1. Click Perform Optimization
2. Click Display Additional Columns
3. Click Compact Mode
4. If needed, click Toggle Display of Plies 2 times
5. The stack is sufficiently homogeneous.
6. The updated set of PCOMPG entries is listed on the next row of the table.
7. Click Save New Entries to save the updated PCOMPG entries.

- Refer to the appendix for additional manufacturing constraints for:
  - Pair ±θ plies
  - Maximum Number of Consecutive Plies
  - Maximum Allowed Angle Difference
  - Force Homogenous Stacking

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Review Updated PCOMPG Entries

1. Click Review
2. The PCOMPG entries have been updated to use the newest optimized stacking sequence

A. If there is a need to rejected the updated PCOMPG entries, click the Remove buttons to reject the new PCOMPG entries.

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Download New BDF Files

1. Click Download
2. Click Download BDF Files

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or contact

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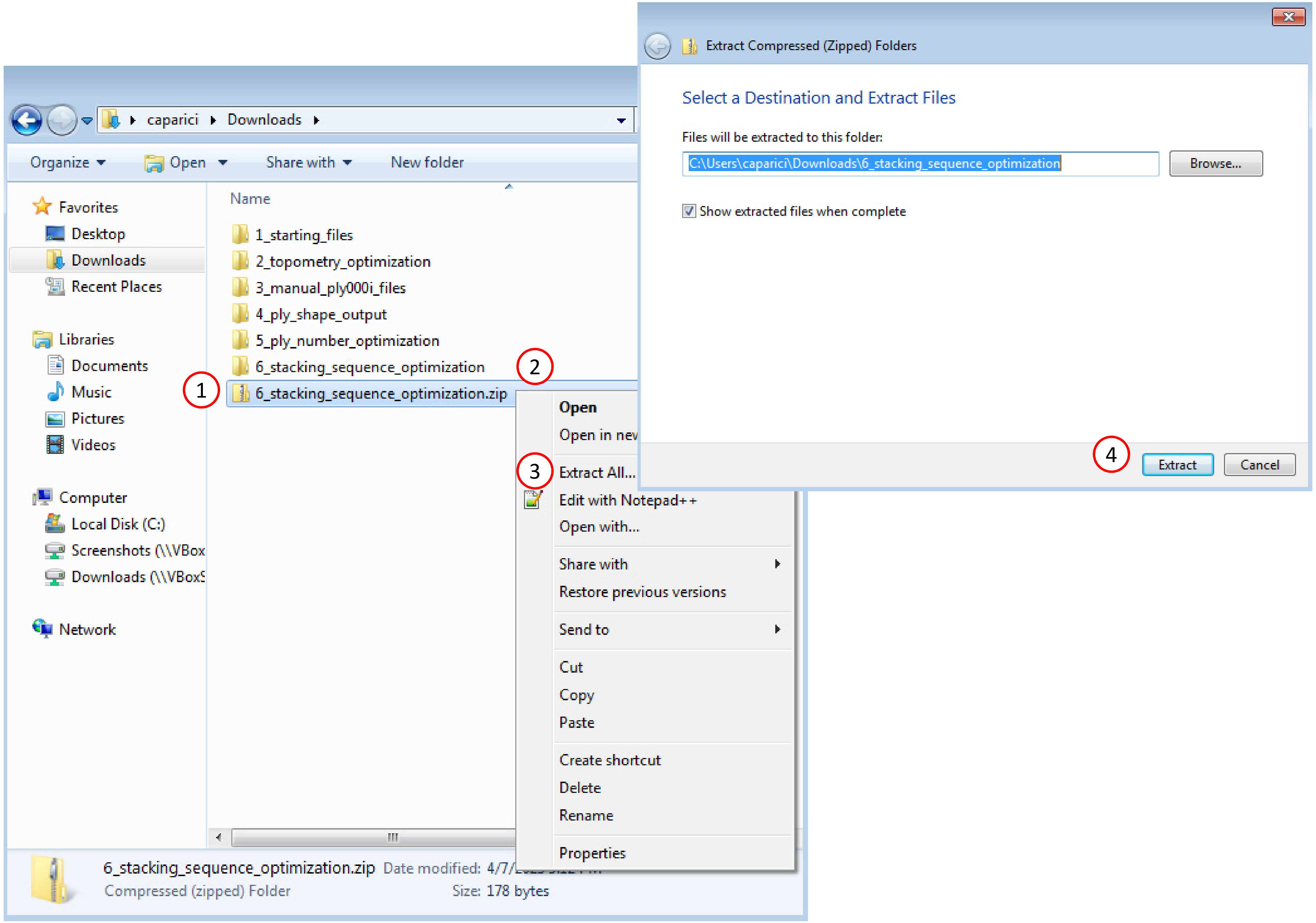
Extract the ZIP

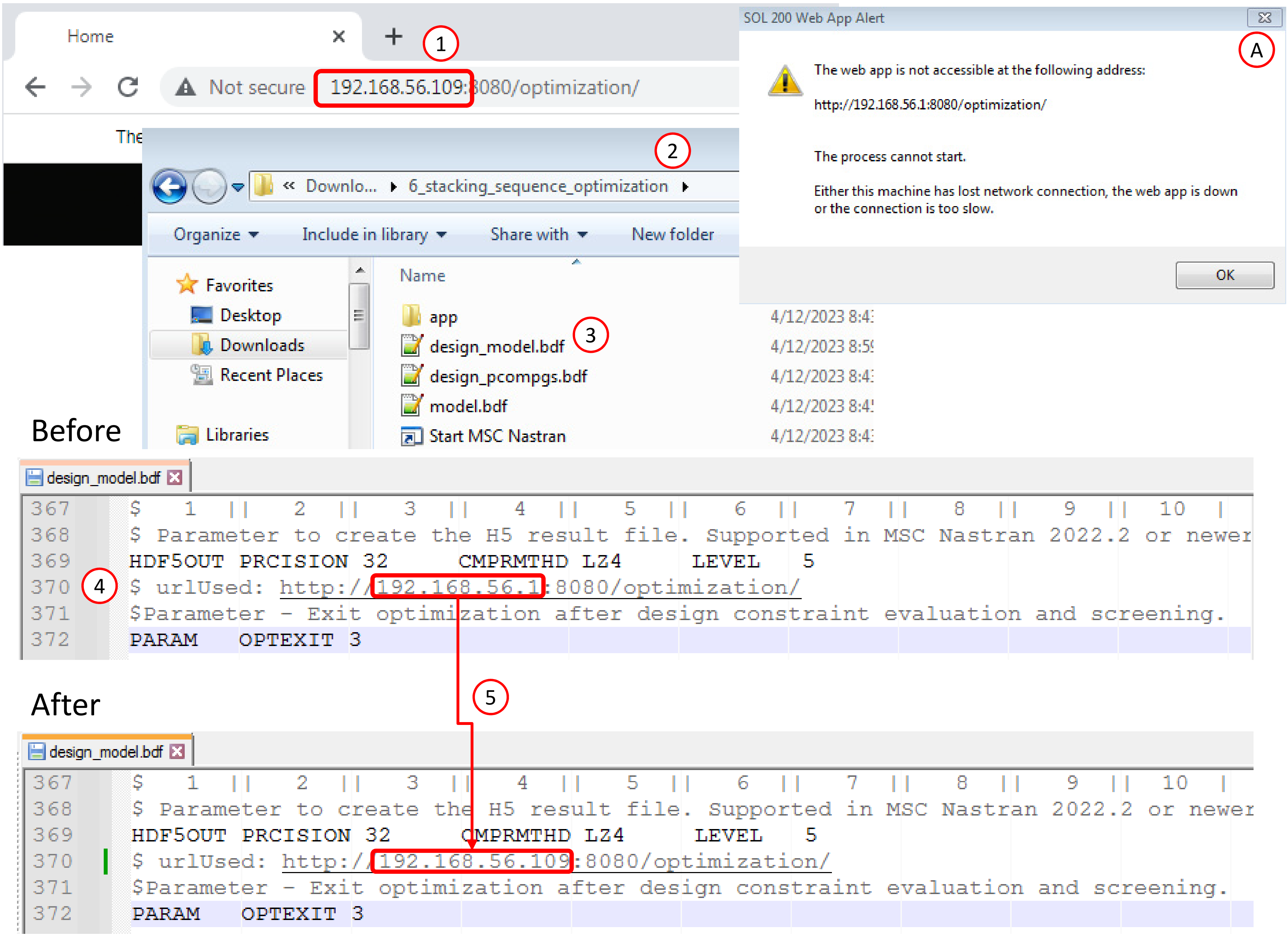
1. Rename the downloaded ZIP to 6_stacking_sequence.zip
2. Right click on the ZIP file
3. Click Extract All
4. Click Extract



Edit Starting File

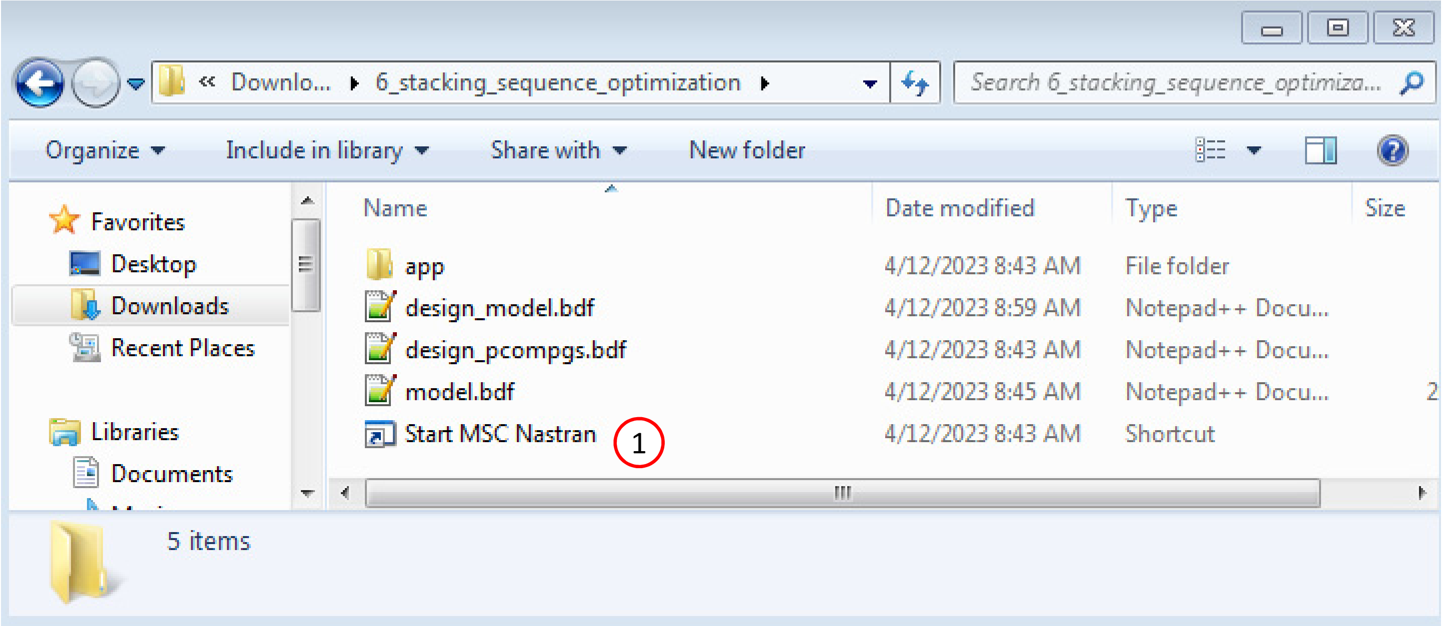
1. Take note of the URL address used
2. Navigate to the directory 6_stacking_sequence_optimization
3. Open this file in a text editor: design_model.bdf
4. Navigate to the line start with this text: $ urlUsed
5. Ensure the URL address is the same as the URL from step 1
6. Save the changes to the text file (not shown)

A. If the URL address in the BDF file is not accessible, the indicated error message will appear and is not desired. The starting BDF files may have been created separately in a different network, so the URL address in the BDF file may be different from the URL you are using. The URL address must be edited to match your URL address.



Start MSC Nastran

1. Click Start MSC Nastran



Status

1. A Status page displays the progress of the optimization

SOL 200 Web App - Status (1)

Home

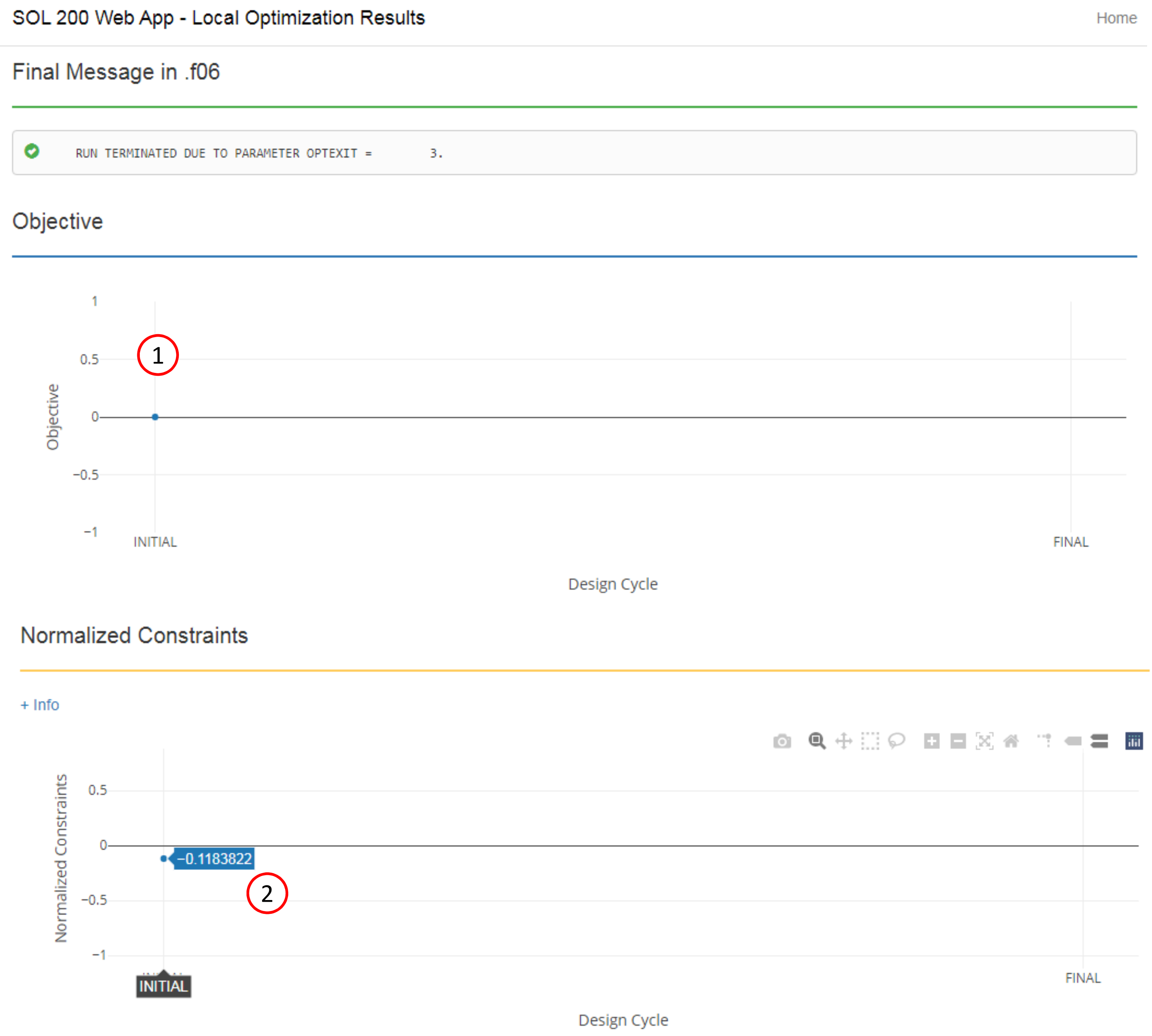
Python MSC Nastran

Status

Name	Status of Job	Design Cycle	RUN TERMINATED DUE TO
model.bdf	Finished	INITIAL	PARAMETER OPTEXIT

Review Optimization Results

1. Only one MSC Nastran analysis was performed, no optimization was performed. The goal of this MSC Nastran run was to confirm the newest stack of plies yields a design that still satisfies the failure index constraints.
2. The max normalized constraint is negative and confirms the new stack does satisfy the design constraints.

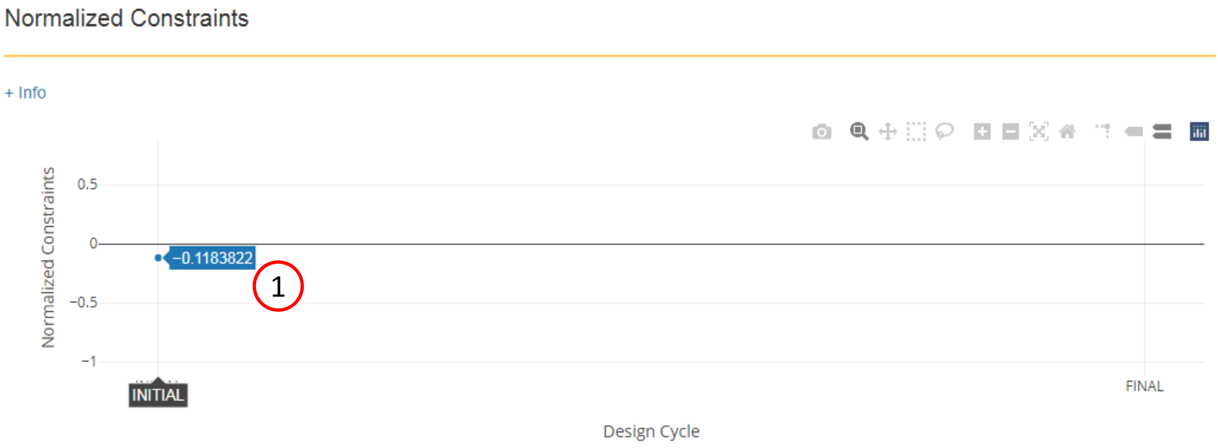


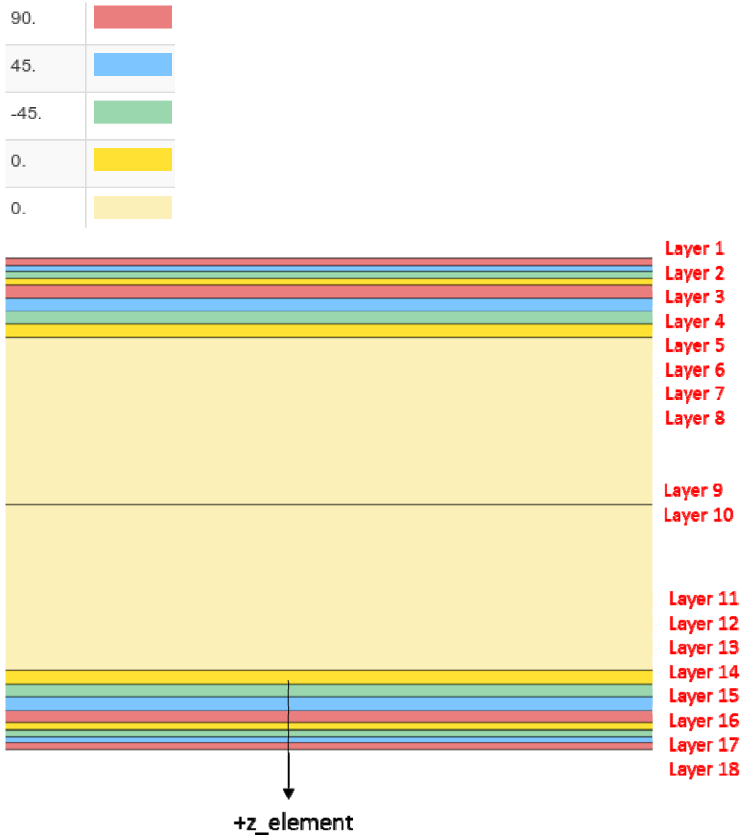
Review Optimization Results

1. The max normalized constraint is ~-.118, indicating the updated composite design still satisfies all the constraints.

If the max normalized constraint is positive, indicating a design constraint is violated, this may be due to the following reason.

- Suppose the original composite defined via the PCOMP entry had the 0° ply as the outer most layer. During a stacking sequence optimization, the 0° plies will be moved throughout the thickness of the composite, which may reduce the stiffness of the composite. In this tutorial, the 0° ply is purposely placed as the 8th layer, not 5th layer. When the stacking sequence optimization is performed and the 0° plies, which were initially on the 5th layer, are moved throughout the composite, the stiffness is increased.
- For responses that depend on stacking sequence order, such as bending, buckling or natural frequencies, it is advised the starting PCOMP NOT have the 0° ply towards the surface of the composite. Move the 0° ply towards the midplane, as was done in this tutorial.






```
PCOMP   1                       90.     HILL
        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
```

Compare the PCOMPG Entries Before and After Stacking Sequence Optimization

1. The PCOMPG entries before and after a stacking sequence optimizations shows that the PCOMPG entries have been updated to use the newest stacking sequence. Note that the symmetry of the composite has been preserved.

Before
(workspace_c/design_pcompgs.bdf)

design_pcompgs.bdf

```
$   1   ||   2   ||   3   ||   4   ||   5   ||   6   |
PCOMPG  2               0.0     90.             HILL
        111000  101     .125    90.             YES
        121000  101     .125    45.             YES
        131000  101     .125    -45.            YES
        141000  101     .125    0.0             YES
        151001  101     .125    90.             YES
        161001  101     .125    45.             YES
        171001  101     .125    -45.            YES
        181001  101     .125    0.0             YES
        181002  101     .125    0.0             YES
        191000  501     3.175   0.0             YES
        2191000 501     3.175   0.0             YES
        2181002 101     .125    0.0             YES
        2181001 101     .125    0.0             YES
        2171001 101     .125    -45.            YES
        2161001 101     .125    45.             YES
        2151001 101     .125    90.             YES
        2141000 101     .125    0.0             YES
        2131000 101     .125    -45.            YES
        2121000 101     .125    45.             YES
        2111000 101     .125    90.             YES
PCOMPG  3               0.0     90.             HILL
        111000  101     .125    90.             YES
        121000  101     .125    45.             YES
        131000  101     .125    -45.            YES
        141000  101     .125    0.0             YES
        151001  101     .125    90.             YES
        161001  101     .125    45.             YES
        162001  101     .125    45.             YES
        171001  101     .125    -45.            YES
        172001  101     .125    -45.            YES
        181001  101     .125    0.0             YES
        181002  101     .125    0.0             YES
```

After
(6_stacking_sequence_optimization/design_pcompgs.bdf)

design_pcompgs.bdf

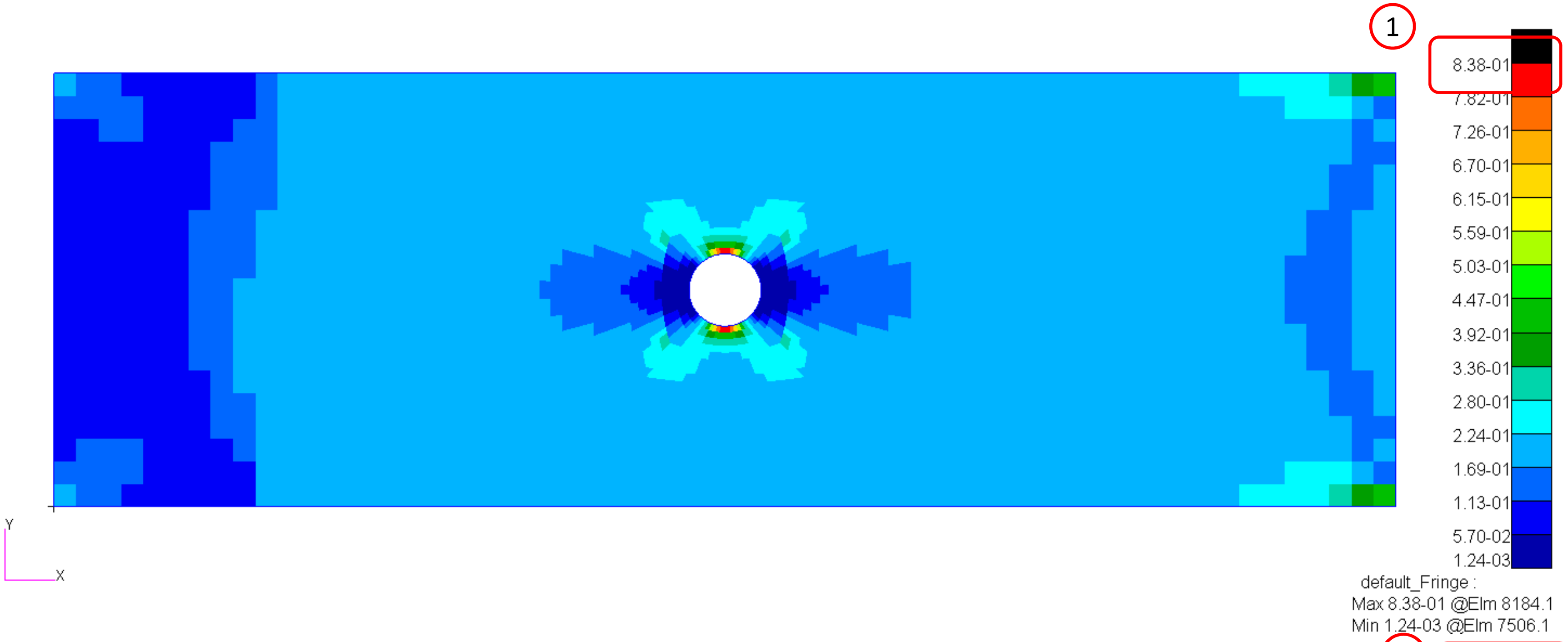
```
$   1   ||   2   ||   3   ||   4   ||   5   ||   6   |
PCOMPG  2               0.0     90.             HILL
        121000  101     .125    45.             YES
        131000  101     .125    -45.            YES
        141000  101     .125    0.0             YES
        111000  101     .125    90.             YES
        161001  101     .125    45.             YES
        171001  101     .125    -45.            YES
        181001  101     .125    0.0             YES
        181002  101     .125    0.0             YES
        151001  101     .125    90.             YES
        191000  501     3.175   0.0             YES
        2191000 501     3.175   0.0             YES
        2151001 101     .125    90.             YES
        2181002 101     .125    0.0             YES
        2181001 101     .125    0.0             YES
        2171001 101     .125    -45.            YES
        2161001 101     .125    45.             YES
        2111000 101     .125    90.             YES
        2141000 101     .125    0.0             YES
        2131000 101     .125    -45.            YES
        2121000 101     .125    45.             YES
PCOMPG  3               0.0     90.             HILL
        121000  101     .125    45.             YES
        131000  101     .125    -45.            YES
        141000  101     .125    0.0             YES
        111000  101     .125    90.             YES
        161001  101     .125    45.             YES
        171001  101     .125    -45.            YES
        181001  101     .125    0.0             YES
        181002  101     .125    0.0             YES
        162001  101     .125    45.             YES
        172001  101     .125    -45.            YES
        182001  101     .125    0.0             YES
```

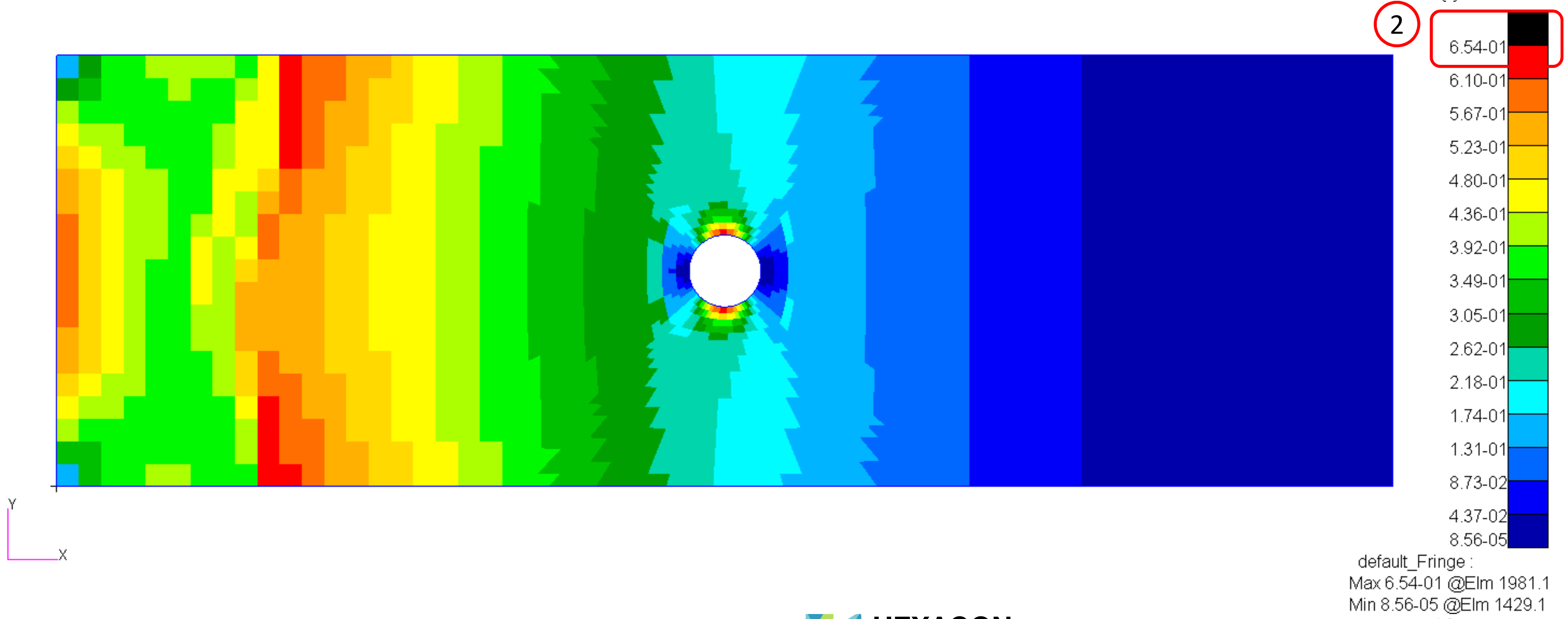
1

Inspect the Newest Failure Indices

Patran is used to confirm the maximum failure index is within the upper allowed limit of .95

1. For subcase 1, the maximum failure index across all plies is .838. This value is OK.
2. For subcase 2, the maximum failure index across all plies is .654. This value is OK.





Summary of Optimized Designs

A comparison is made between the starting and final composite designs from Phase D and E. 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, ply number and stacking sequence 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 (OK)	.856 (OK)	.654 (OK)

Inspect the Newest Composite

1. Open a new Viewer session
2. Click Upload BDF
3. Click Select files
4. Navigate to directory 6_stacking_sequence
5. Select the indicated files
6. Click Open
7. Click Upload files
8. Click Background Color (Optional)

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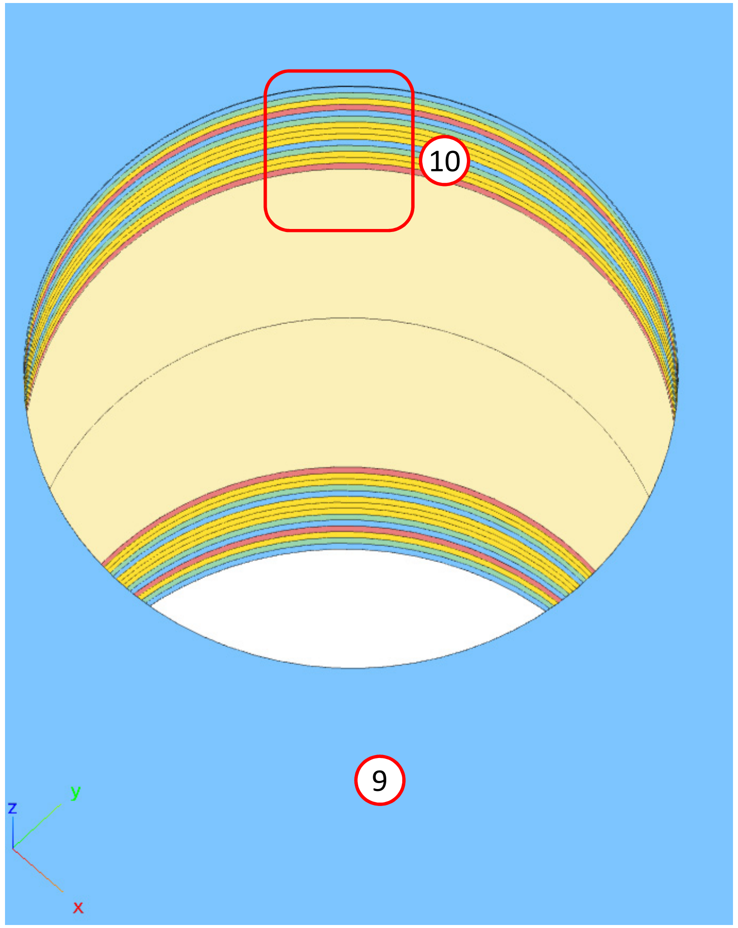
Inspect the Newest Composite

1. Click Background Color
2. Click Model Display Panel
3. For the Property Name column, search the table for “gply”
4. Click the indicated button to display the ply thicknesses
5. Click the indicated button to display the wireframes
6. Click the indicated button to color the plies according to THETA
7. Click Center Model
8. Click Fit Model
9. Click and hold the right mouse button and move the mouse to translate the model. Click and hold the left mouse button and move the mouse to rotate the model.
10. Notice that the plies reflect the new stacking sequence.



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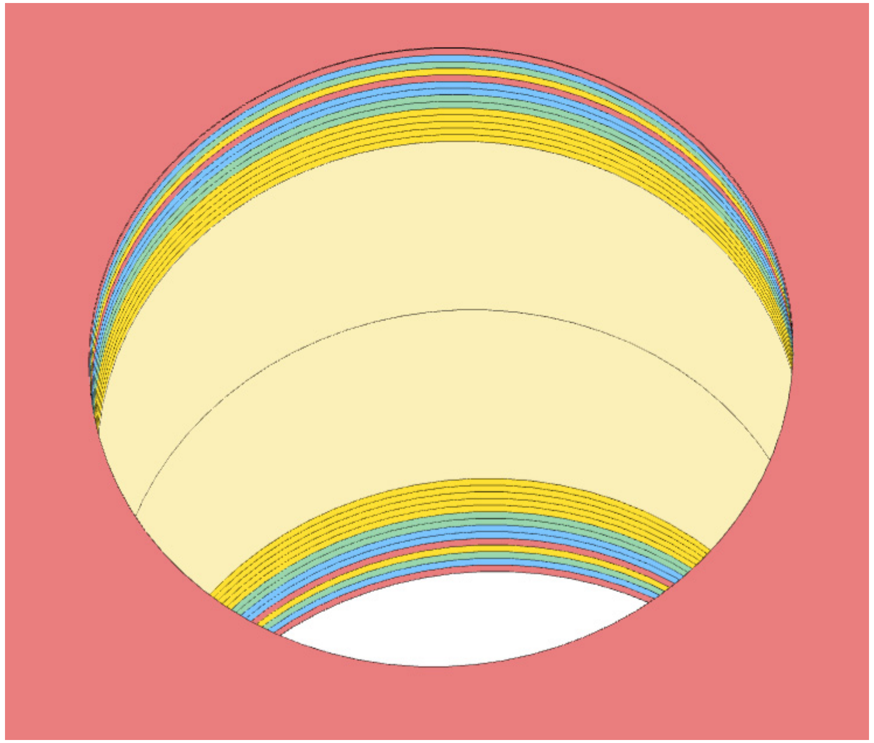
Inspect the Newest Composite

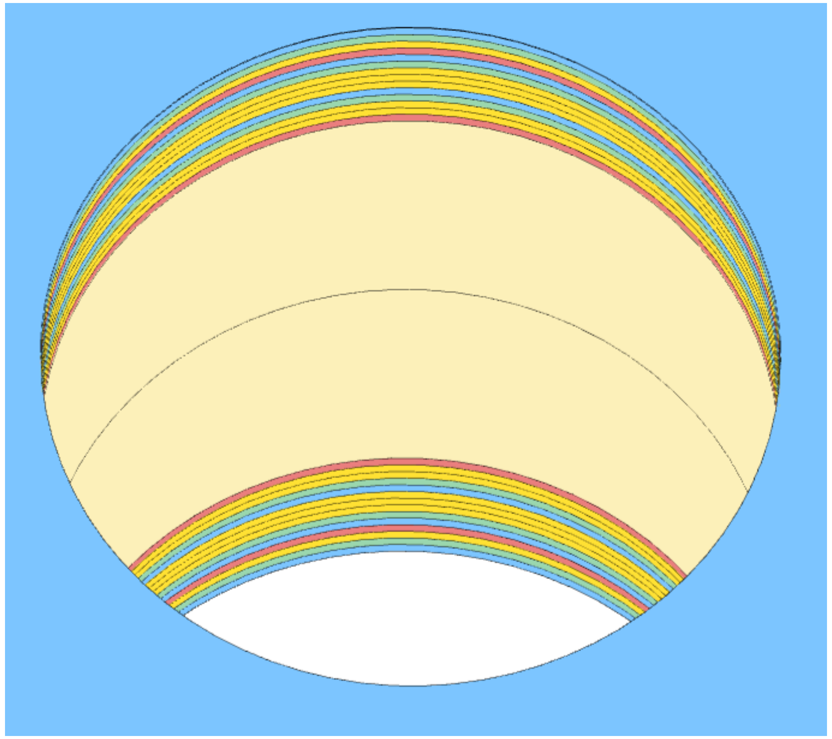
A comparison is shown of the plies before and after stacking sequence optimization

90
45
-45
0
0 (Core)

Before



After



Export of Ply Table for Catia Composite Design

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.

The Engineering Lab

Open the Stacking Sequence Web App

1. Navigate to the Composites section
2. Click Stacking Sequence

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Upload Files

1. Click Select files
2. Navigate to 6_stacking_sequence_optimization
3. Select the indicated files
4. Click Open
5. Click Upload files

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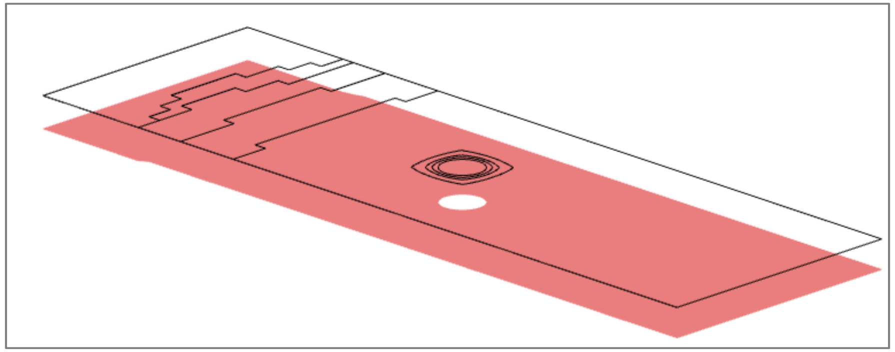
Select a Stack

1. Click Select Stack
2. Select Multiple Stacks
3. Select GPLY 111000

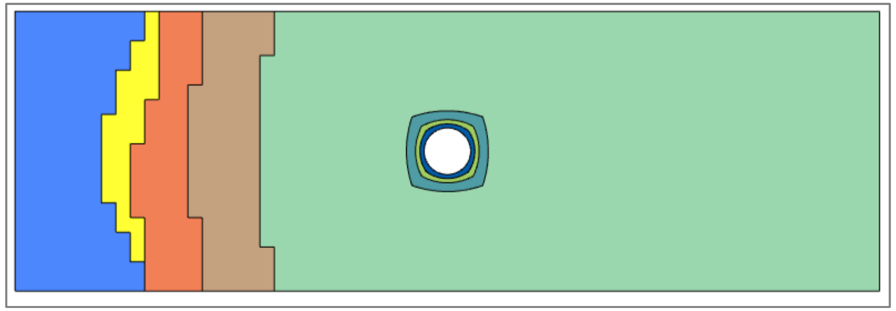
Why is GPLY 111000 selected?

- GPLY 111000 is used by PCOMPG 2-7 and is used by the entire model.
- GPLY 181001 is only used by PCOMPG 3 and covers only a small portion of the model.
- When you select a GPLY, all the associated PCOMPGs are loaded and updated after the stacking sequence optimization. If GPLY 181001 is selected, only PCOMPG 3 is loaded and updated by stacking sequence optimization. Since GPLY 111000 is selected, all PCOMPGs are loaded and updated by the stacking sequence optimization.

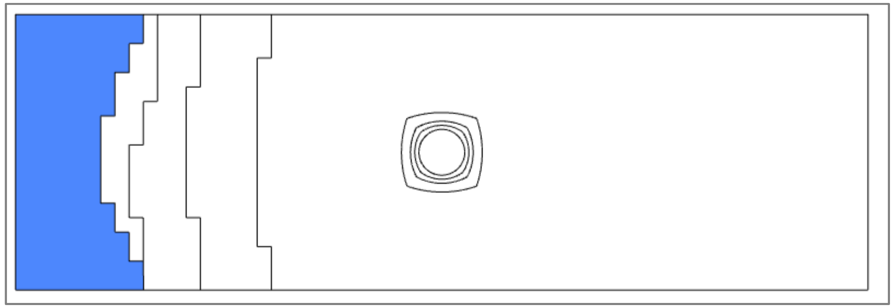
GPLY 111000



PCOMPG 2-9



PCOMPG 3



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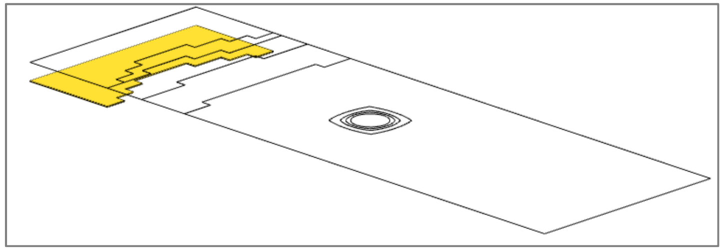
GPLY 181001



Inspect the Stack

1. Click Optimize
2. Scroll to the Stack section

The following steps change the appearance of the Stack table.

3. Click Display Additional Columns
4. Click Toggle Display of Plies
5. Click Compact Mode

Note that there are 6 PCOMPG columns.

6. Click Output Ply Table to download a ply_table.csv file

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Ply Table for Catia Composite Design

1. Open ply_table.csv in Excel

The web app has no access to the Catia database. Consequently, none of the information from the Catia database is available to the web app, so the CSV file will have some columns with empty values. The CSV file must be manually updated to use the same names as defined in the Catia database.

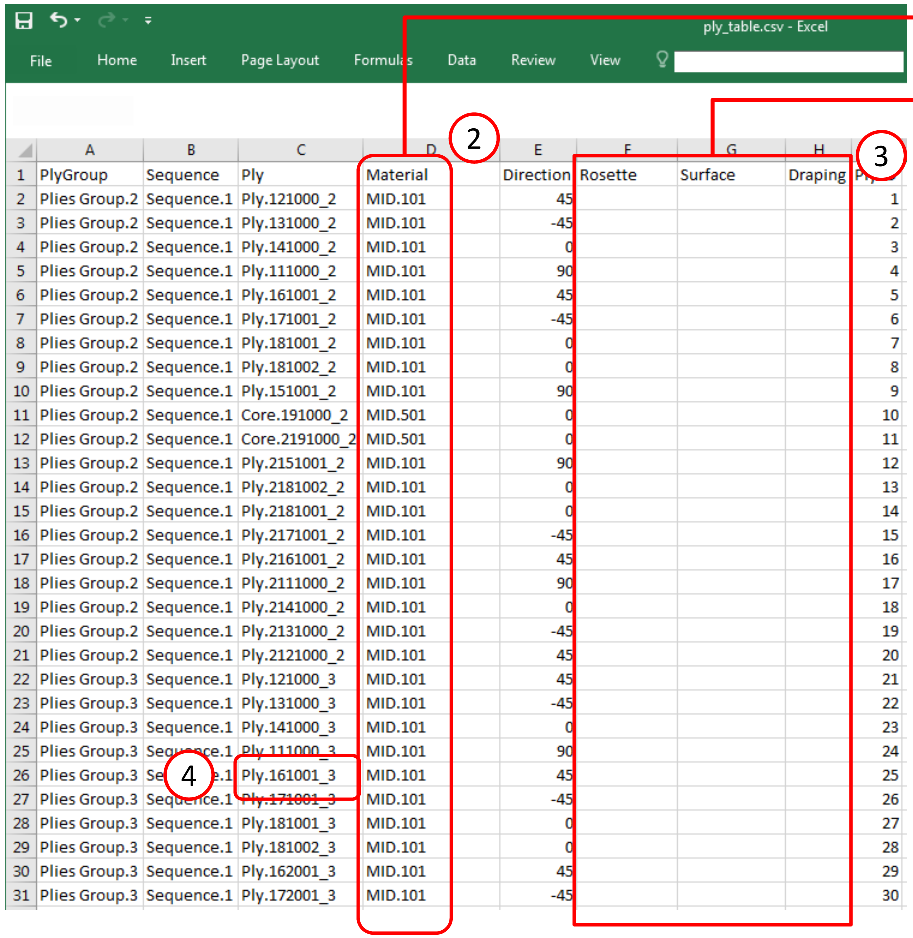
2. An example is shown to illustrate one possibility of how the CSV file is updated to use names defined in the Catia database.

3. Save the CSV file as an XLS file (not shown). The new XLS file may now be imported to Catia Composite Design.

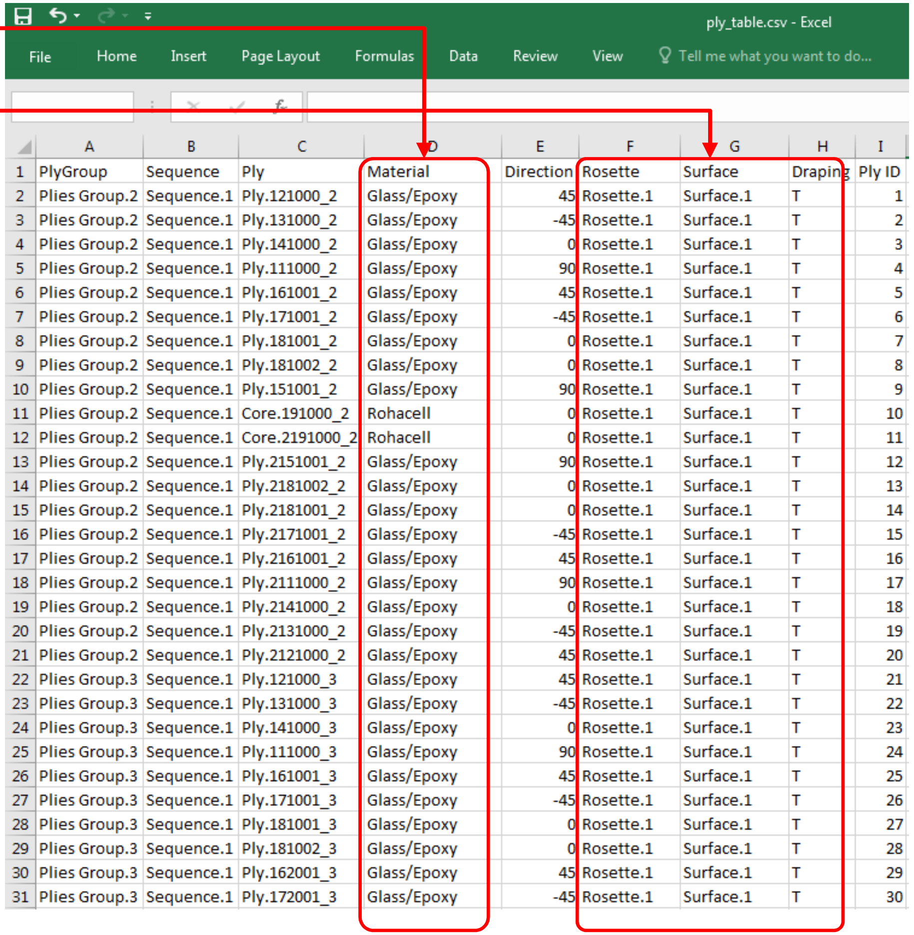
Since the stack had 8 PCOMPG entries (PCOMPG 2, 3, … 9), the CSV file has 6 Plies Groups: Plies Group.2, Plies Group.3, …, Plies Group.7.

4. The Ply names are in the following format: Ply.GPLYID_PCOMPGID. For example, Ply.161001_3 corresponds to the ply for GPLY ID 161001 for PCOMPG 3. A core layer has the format Core.GPLYID_PCOMPGID.

1



	A	B	C	D	E	F	G	H	
1	PlyGroup	Sequence	Ply	Material	Direction	Rosette	Surface	Draping	[illegible]
2	Plies Group.2	Sequence.1	Ply.121000_2	MID.101	45				1
3	Plies Group.2	Sequence.1	Ply.131000_2	MID.101	-45				2
4	Plies Group.2	Sequence.1	Ply.141000_2	MID.101	0				3
5	Plies Group.2	Sequence.1	Ply.111000_2	MID.101	90				4
6	Plies Group.2	Sequence.1	Ply.161001_2	MID.101	45				5
7	Plies Group.2	Sequence.1	Ply.171001_2	MID.101	-45				6
8	Plies Group.2	Sequence.1	Ply.181001_2	MID.101	0				7
9	Plies Group.2	Sequence.1	Ply.181002_2	MID.101	0				8
10	Plies Group.2	Sequence.1	Ply.151001_2	MID.101	90				9
11	Plies Group.2	Sequence.1	Core.191000_2	MID.501	0				10
12	Plies Group.2	Sequence.1	Core.2191000_2	MID.501	0				11
13	Plies Group.2	Sequence.1	Ply.2151001_2	MID.101	90				12
14	Plies Group.2	Sequence.1	Ply.2181002_2	MID.101	0				13
15	Plies Group.2	Sequence.1	Ply.2181001_2	MID.101	0				14
16	Plies Group.2	Sequence.1	Ply.2171001_2	MID.101	-45				15
17	Plies Group.2	Sequence.1	Ply.2161001_2	MID.101	45				16
18	Plies Group.2	Sequence.1	Ply.2111000_2	MID.101	90				17
19	Plies Group.2	Sequence.1	Ply.2141000_2	MID.101	0				18
20	Plies Group.2	Sequence.1	Ply.2131000_2	MID.101	-45				19
21	Plies Group.2	Sequence.1	Ply.2121000_2	MID.101	45				20
22	Plies Group.3	Sequence.1	Ply.121000_3	MID.101	45				21
23	Plies Group.3	Sequence.1	Ply.131000_3	MID.101	-45				22
24	Plies Group.3	Sequence.1	Ply.141000_3	MID.101	0				23
25	Plies Group.3	Sequence.1	Ply.111000_3	MID.101	90				24
26	Plies Group.3	Se[illegible]e.1	Ply.161001_3	MID.101	45				25
27	Plies Group.3	Sequence.1	Ply.171001_3	MID.101	-45				26
28	Plies Group.3	Sequence.1	Ply.181001_3	MID.101	0				27
29	Plies Group.3	Sequence.1	Ply.181002_3	MID.101	0				28
30	Plies Group.3	Sequence.1	Ply.162001_3	MID.101	45				29
31	Plies Group.3	Sequence.1	Ply.172001_3	MID.101	-45				30



	A	B	C	D	E	F	G	H	I
1	PlyGroup	Sequence	Ply	Material	Direction	Rosette	Surface	Draping	Ply ID
2	Plies Group.2	Sequence.1	Ply.121000_2	Glass/Epoxy	45	Rosette.1	Surface.1	T	1
3	Plies Group.2	Sequence.1	Ply.131000_2	Glass/Epoxy	-45	Rosette.1	Surface.1	T	2
4	Plies Group.2	Sequence.1	Ply.141000_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	3
5	Plies Group.2	Sequence.1	Ply.111000_2	Glass/Epoxy	90	Rosette.1	Surface.1	T	4
6	Plies Group.2	Sequence.1	Ply.161001_2	Glass/Epoxy	45	Rosette.1	Surface.1	T	5
7	Plies Group.2	Sequence.1	Ply.171001_2	Glass/Epoxy	-45	Rosette.1	Surface.1	T	6
8	Plies Group.2	Sequence.1	Ply.181001_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	7
9	Plies Group.2	Sequence.1	Ply.181002_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	8
10	Plies Group.2	Sequence.1	Ply.151001_2	Glass/Epoxy	90	Rosette.1	Surface.1	T	9
11	Plies Group.2	Sequence.1	Core.191000_2	Rohacell	0	Rosette.1	Surface.1	T	10
12	Plies Group.2	Sequence.1	Core.2191000_2	Rohacell	0	Rosette.1	Surface.1	T	11
13	Plies Group.2	Sequence.1	Ply.2151001_2	Glass/Epoxy	90	Rosette.1	Surface.1	T	12
14	Plies Group.2	Sequence.1	Ply.2181002_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	13
15	Plies Group.2	Sequence.1	Ply.2181001_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	14
16	Plies Group.2	Sequence.1	Ply.2171001_2	Glass/Epoxy	-45	Rosette.1	Surface.1	T	15
17	Plies Group.2	Sequence.1	Ply.2161001_2	Glass/Epoxy	45	Rosette.1	Surface.1	T	16
18	Plies Group.2	Sequence.1	Ply.2111000_2	Glass/Epoxy	90	Rosette.1	Surface.1	T	17
19	Plies Group.2	Sequence.1	Ply.2141000_2	Glass/Epoxy	0	Rosette.1	Surface.1	T	18
20	Plies Group.2	Sequence.1	Ply.2131000_2	Glass/Epoxy	-45	Rosette.1	Surface.1	T	19
21	Plies Group.2	Sequence.1	Ply.2121000_2	Glass/Epoxy	45	Rosette.1	Surface.1	T	20
22	Plies Group.3	Sequence.1	Ply.121000_3	Glass/Epoxy	45	Rosette.1	Surface.1	T	21
23	Plies Group.3	Sequence.1	Ply.131000_3	Glass/Epoxy	-45	Rosette.1	Surface.1	T	22
24	Plies Group.3	Sequence.1	Ply.141000_3	Glass/Epoxy	0	Rosette.1	Surface.1	T	23
25	Plies Group.3	Sequence.1	Ply.111000_3	Glass/Epoxy	90	Rosette.1	Surface.1	T	24
26	Plies Group.3	Sequence.1	Ply.161001_3	Glass/Epoxy	45	Rosette.1	Surface.1	T	25
27	Plies Group.3	Sequence.1	Ply.171001_3	Glass/Epoxy	-45	Rosette.1	Surface.1	T	26
28	Plies Group.3	Sequence.1	Ply.181001_3	Glass/Epoxy	0	Rosette.1	Surface.1	T	27
29	Plies Group.3	Sequence.1	Ply.181002_3	Glass/Epoxy	0	Rosette.1	Surface.1	T	28
30	Plies Group.3	Sequence.1	Ply.162001_3	Glass/Epoxy	45	Rosette.1	Surface.1	T	29
31	Plies Group.3	Sequence.1	Ply.172001_3	Glass/Epoxy	-45	Rosette.1	Surface.1	T	30

End of Tutorial

Appendix

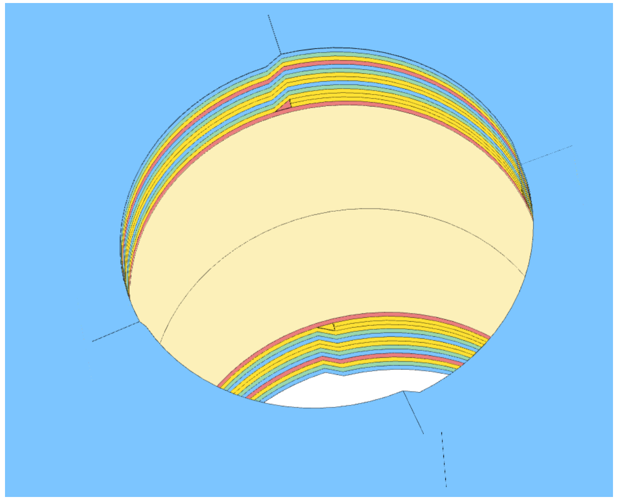
Appendix Contents

- Options - Stacking Sequence Optimization

Options - Stacking Sequence Optimization

Capabilities - Stacking Sequence Optimization

- Pair ±θ plies
- Maximum Number of Consecutive Plies
- Maximum Allowed Angle Difference
- Force Homogenous Stacking
- Update of multiple PCOMPGs



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Available Manufacturing Constraints for Stacking Sequence Optimization

1. Symmetry
2. Maximum Allowed Angle Difference
3. Maximum Number of Consecutive Plies
4. Homogeneous Constraint (Minimum of M θ° Plies Per N Plies)
5. Pairing
6. Perform Optimization

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Pairing

- Pair angles
    1. SAME – Same order of signs
    2. REVERSE – Alternating signs
- Pair arbitrary angles, e.g. ±1, ±2, ..., ±45, .., ±60, etc.

Before

Ply	Theta	GPLY ID
1	45°	1
2	45°	2
3	-45°	5
4	-45°	6
5	60°	9
6	60°	10
7	-60°	13
8	-60°	14
9	-60°	16
10	-60°	15
11	60°	12
12	60°	11
13	-45°	8
14	-45°	7
15	45°	4
16	45°	3

After

Ply	Theta	GPLY ID
1	45°	1
2	-45°	5
3	45°	2
4	-45°	6
5	60°	9
6	-60°	13
7	-60°	14
8	60°	10
9	60°	12
10	-60°	16
11	-60°	15
12	60°	
13	-45°	
14	45°	
15	-45°	
16	45°	

Maximum Consecutive Plies

This option limits the number of consecutive plies.

Before

Ply	Theta	GPLY ID
1	0°	1
2	0°	2
3	0°	3
4	0°	4
5	0°	5
6	0°	6
7	90°	7
8	90°	8
9	90°	9
10	90°	10
11	90°	11
12	90°	12
13	90°	13

No more than 1 consecutive 90-degree plies

After

Ply	Theta	GPLY ID
1	90°	13
2	0°	3
3	90°	8
4	0°	2
5	90°	9
6	0°	5
7	90°	10
8	0°	6
9	90°	12
10	0°	4
11	90°	7
12	0°	1
13	90°	11

No more than 2 consecutive 90-degree plies

After

Ply	Theta	GPLY ID
1	90°	10
2	0°	1
3	90°	7
4	90°	13
5	0°	2
6	0°	5
7	0°	3
8	90°	12
9	90°	11
10	0°	6
11	90°	8
12	0°	4
13	90°	9

Homogenous Constraint

Obtain close to homogenous stack

1. In this example, the 90-degree ply is constrained to appear once every 4 plies

Before

Ply	Theta	GPLY ID
1	90°	1
2	90°	2
3	90°	3
4	0°	4
5	0°	5
6	0°	6
7	0°	7
8	0°	8
9	0°	9
10	0°	10
11	0°	11
12	0°	12

After

Ply	Theta	GPLY ID
1	90°	1
2	0°	8
3	0°	9
4	0°	4
5	90°	2
6	0°	5
7	0°	6
8	0°	7
9	90°	3
10	0°	10
11	0°	11
12	0°	12

Maximum Allowable Angle Difference Between Adjacent Plies

This option allows you to limit adjacent plies to be within a specified angle difference.

1. In this example, the maximum allowed angle difference between adjacent plies is 5.0. The optimizer yields a stacking sequence that honors this manufacturing constraint.

Before

Ply	Theta	GPLY ID
1	5°	1
2	10°	2
3	20°	3
4	30°	4
5	40°	5
6	15°	6
7	25°	7
8	35°	8
9	45°	9
10	0°	10

45 - 0 = 45 $\nleq$ 5 (NOT OK)

After

Ply	Theta	GPLY ID
1	45°	9
2	40°	5
3	35°	8
4	30°	4
5	25°	7
6	20°	3
7	15°	6
8	10°	2
9	5°	1
10	0°	10

All $\Delta_{\theta i,\, \theta i-1} \leq 5$ (OK)

Ply Controls

1. Move plies manually
2. Fix plies
3. Fix core
4. Enforce symmetry (Not shown)

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Maintain Updated Stacking Sequence Globally

- The order of plies must be consistent throughout the component. The Stacking Sequence web app automatically updates the stacking sequence throughout the PCOMPG entries.