Workshop – Composite Panel – Phase D – Core Shape and Core Thickness Optimization

AN MSC NASTRAN SOL 200 TUTORIAL

Composite Workshop

This workshop is phase D of a 3-phase workshop.

Phase B

Workshop – Composite Panel – Phase B – Baseline Core Thickness Optimization

- Perform a core thickness optimization with a constant thickness core
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

Phase C

Workshop – Composite Panel – Phase C – Topometry Optimization to Determine Optimal Core Shape

- Generate PLY000i Files via Topometry Optimization
- Tools Used: Patran, MSC Nastran and SOL 200 Web App

Phase D

Workshop – Composite Panel – Phase D – Core Shape and Core Thickness Optimization

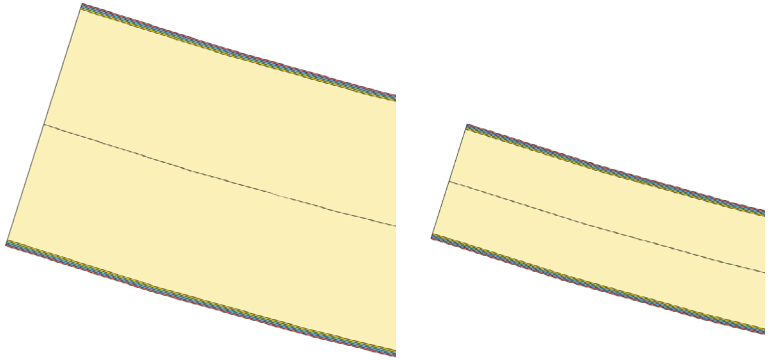
- Input BDF and PLY000i Files
- Create Core Shapes
- Perform Core Thickness Optimization
- Inspect Core
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

Baseline Core Thickness Optimization → Core Shape Optimization → Core Thickness Optimization

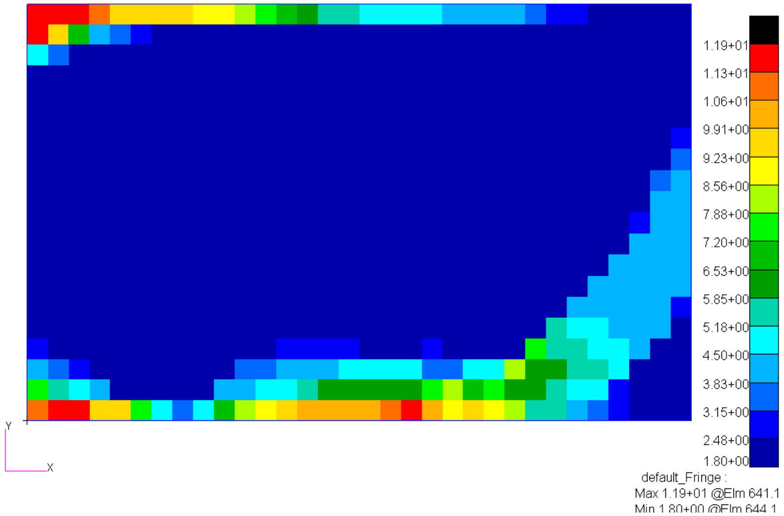
Composite Workshop

This workshop is phase D of a 3-phase workshop.

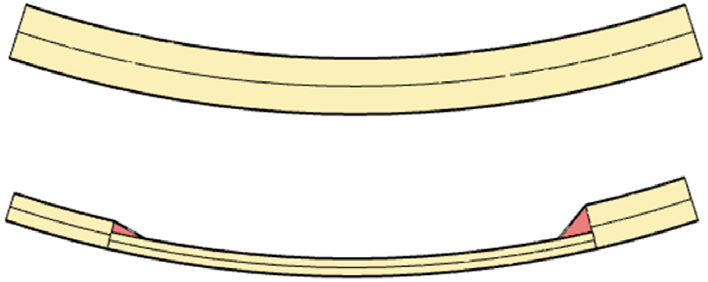
Phase B



Phase C



Phase D



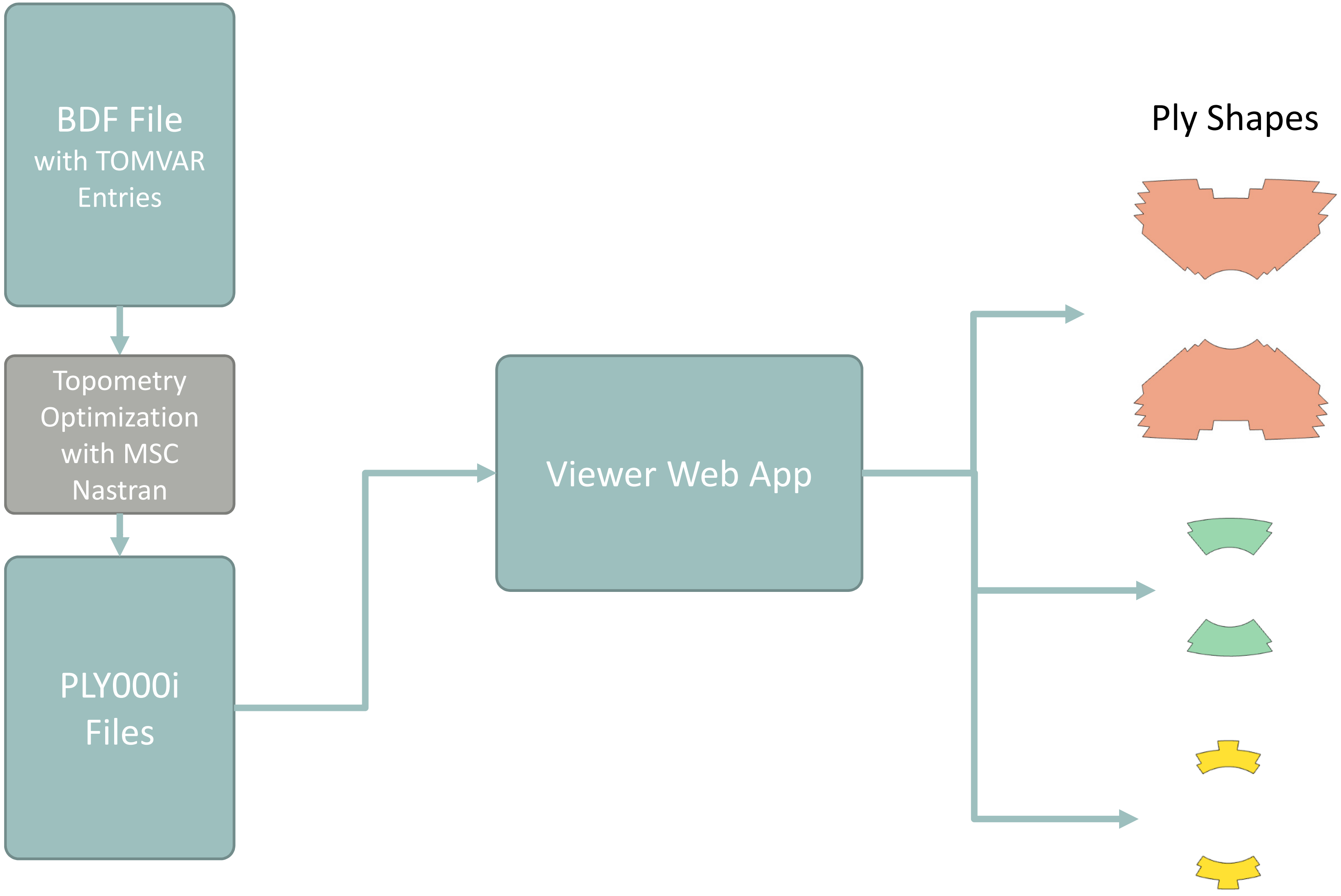
Baseline Core Thickness Optimization

Core Shape Optimization

Core Thickness Optimization

Goal: Construct Optimal Core Shapes and Perform Core Thickness Optimization

- The goal is to construct core shapes that produce a lightweight composite but satisfy buckling constraints.
- This tutorial discusses how to operate the Viewer web app to construct new optimized core shapes and perform a core thickness optimization.
- The word “core” and “ply” are used interchangeably throughout this exercise.



Summary of Optimized Designs

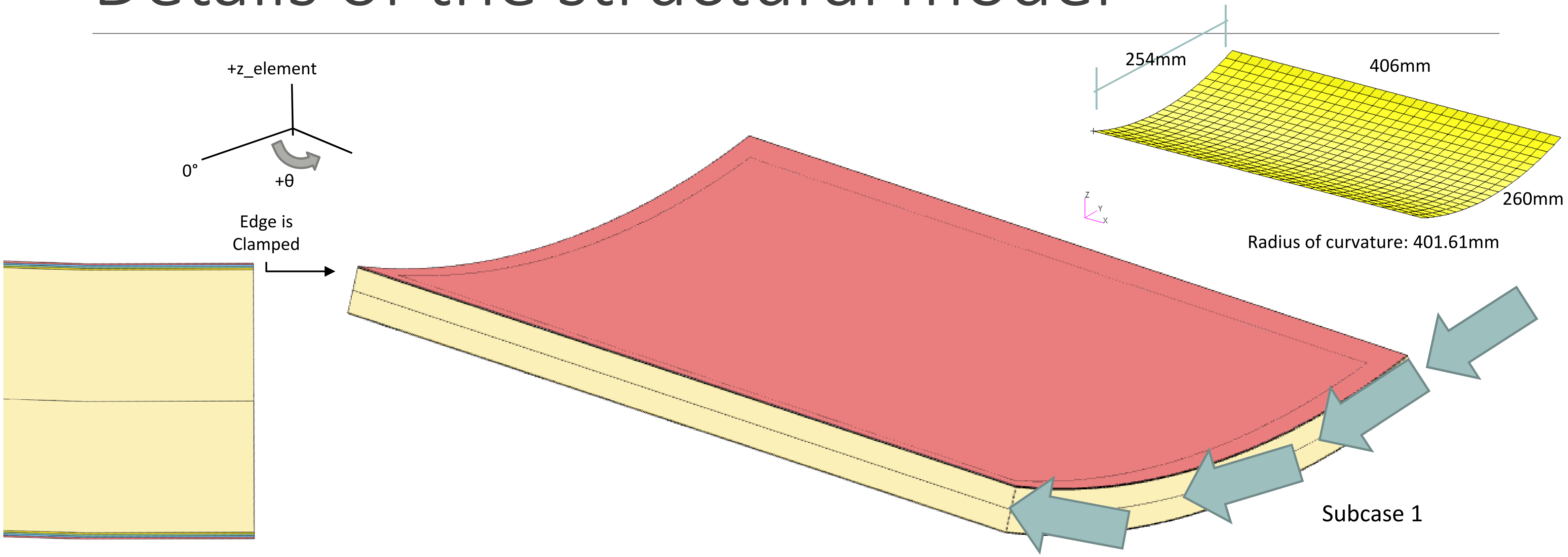
By the end of this tutorial, the mass of the new composite panel is expected to be reduced by approximately 23% .

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

1. ~23% mass savings. The mass of the core was reduced from 2.203330E-04 to 1.70E-04.
2. In both designs, the buckling load factor is greater than 1.0, so both designs are feasible.

	Starting Design	Design After Topometry Optimization	Design After Core Shape and Core Number Optimization
	Tutorial Phase B	Tutorial Phase C	Tutorial Phase D
Total Mass	3.9503E-04	2.97E-4	
Mass of Non-design Region (Plies)	1.746926E-04	1.746926E-04	
Mass of Design Region (Core)	**2.203330E-04**	**1.22E-04**	
Buckling Load Factor, Subcase 2	1.064771 (OK)	9.9758E-01 (NOT OK)	

Details of the structural model

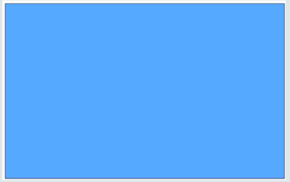
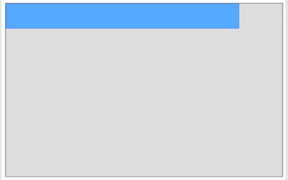
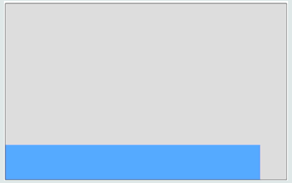


$[90/+45/-45/0/\ 0_{core}]_s$

Using PLY000i Files to Create Optimal Ply Shapes

- The data contained in PLY000i files, e.g. model.ply0005, are critical to construct optimal ply shapes. BDF and PLY000i files are used in this tutorial to construct new optimal ply shapes.
- The SOL 200 Web App's Viewer is used to create new ply shapes.

Ply Shape

Layer, Theta	Ply Shape Candidate 1 (Not used)	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 0° (Core)	151000, 2151000 	152000, 2152000 	153000, 2153000 	154000, 2154000 	185000, 2185000 

- Each ply shape candidate is assigned a unique GPLY ID, e.g. 111000, 2111000. For more details on the GPLY ID numbering convention, refer to the appendix, section *GPLY ID Numbering Convention (sPLC00).*
- Ply shapes are created based on the data contained in the PLY000 files. The PLY000i files are generated by Topometry Optimization or may be created manually, as done in this tutorial. Alternatively, both methods may be combined for a hybrid method.
- Some GPLY IDs have a number 2 as a suffix. This composite is symmetric and the suffix of 2 indicates a symmetric ply. For example, GPLY ID 151000 has a corresponding 2151000 mirror ply.

Optimization Problem Statement

Design Variables

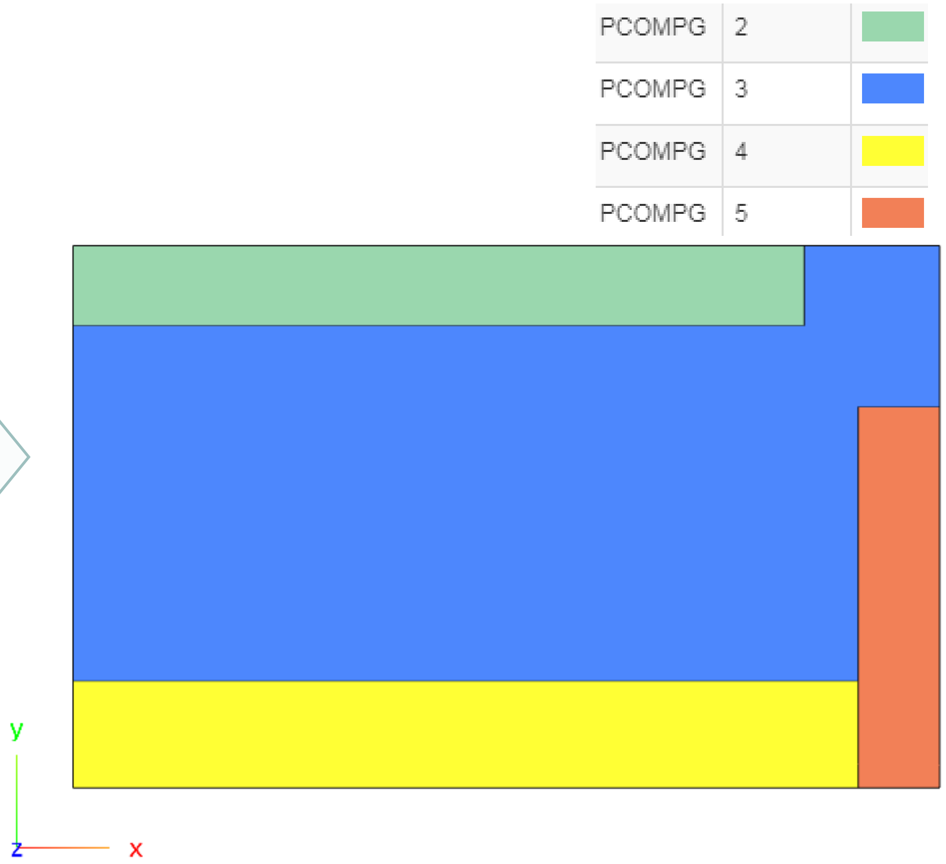
y1: Thickness of core layers for 0°, GPLY IDs: 152000, 2152000

y2: Thickness of core layers for 0°, GPLY IDs: 153000, 2153000

y3: Thickness of core layers for 0°, GPLY IDs: 154000, 2154000

y4: Thickness of core layers for 0°, GPLY IDs: 155000, 2155000

The core is allowed to range between 6mm and 50mm. Since the composite is symmetric, the variables range between 3mm and 25mm. The final thickness value is allowed to be in increment of 1mm.



Design Objective

Minimize r0: weight

Design Constraints

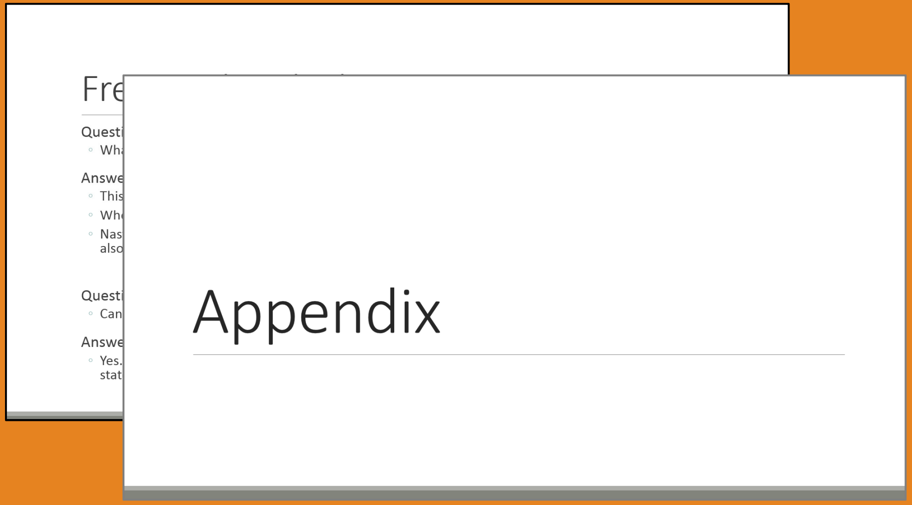
r1: 1st buckling load factor

$1.0 < r1$

More Information Available in the Appendix

The Appendix includes information regarding the following:

- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)



Contact me

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

christian@ the-engineering-lab.com

Tutorial

Tutorial Overview

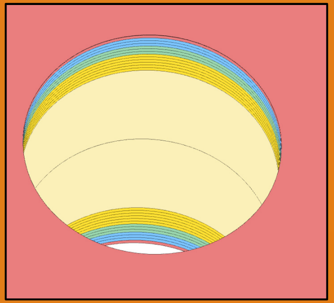
1. Part 1 – Core Shape Creation
2. Part 2 – Core Thickness Optimization
3. Part 3 – View New Core Thickness

Special Topics Covered

Core Shape Editing - The current composite panel uses a constant thickness core. This tutorial discusses a procedure to segment the core and each core will be sized to a different thickness. Ultimately, the goal is to minimize the weight of the composite.

Core Thickness Optimization – Once multiple core segments are defined, a core thickness optimization is performed for each segment.

Core Thickness Inspection - Finally, the final composite core and plies are visually inspected.



SOL 200 Web App Capabilities

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

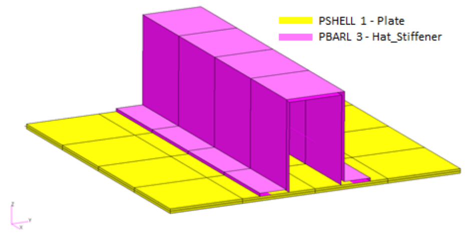
Compatibility

- 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.

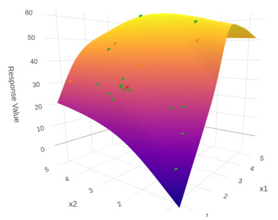
Benefits

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

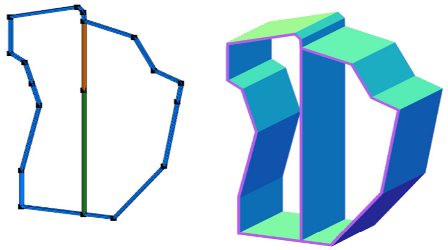
Web Apps



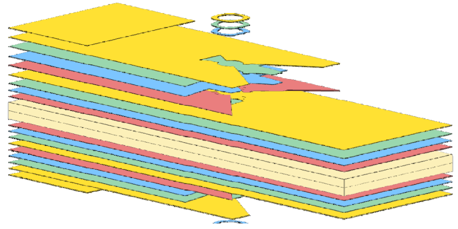
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



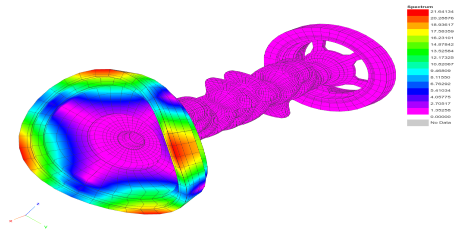
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



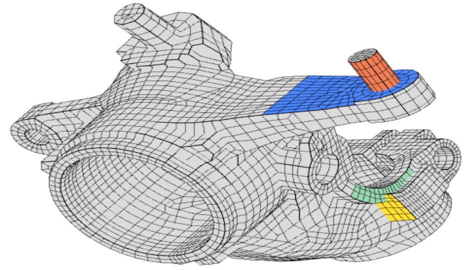
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



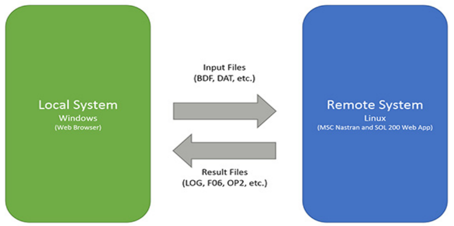
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



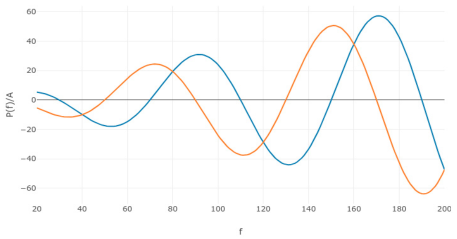
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



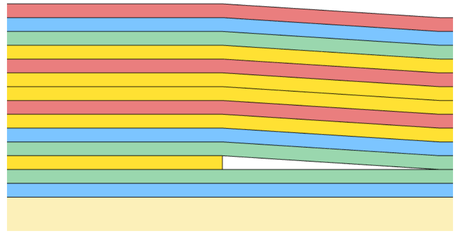
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



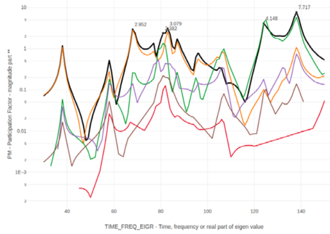
Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



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



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



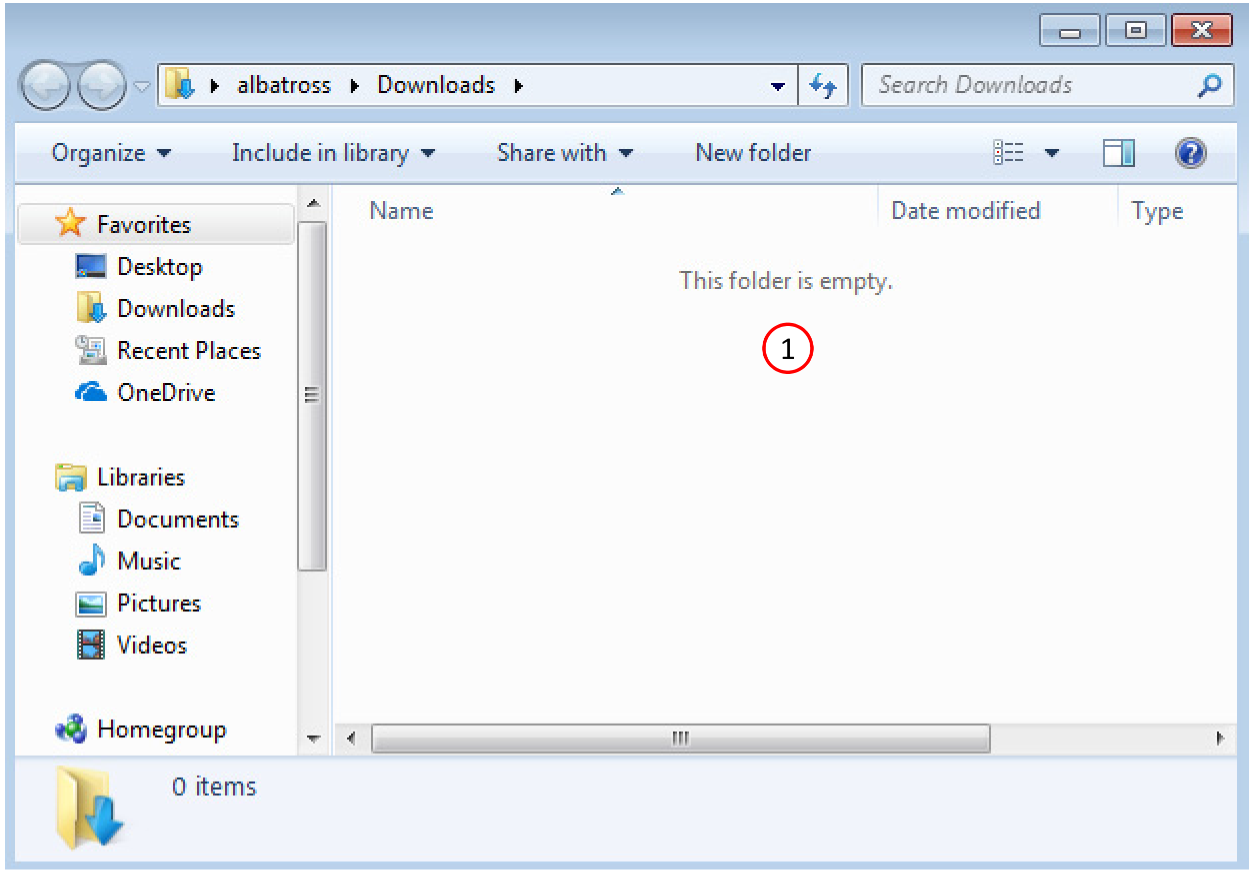
HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

Part 1 – Core Shape Creation

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.

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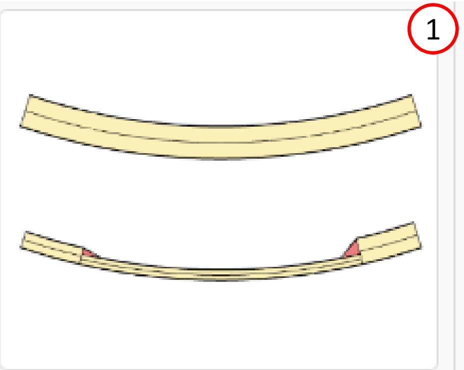
Obtain Starting Files

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.

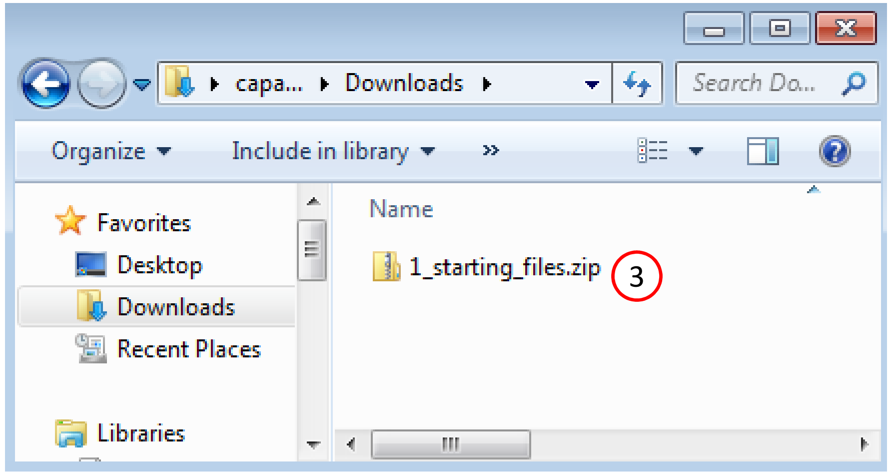


1 **Composite Panel – Phase D – Core Shape and Core Thickness Optimization**

This tutorial details the process to build optimal core shapes and perform a core thickness optimization. The optimal core shapes are constructed to follow the contours of thickness results generated by a topometry optimization. The core thickness optimization involves minimizing weight and constraining the buckling load factor. The PLY000i files and BDF files from the previous tutorial, phase C, are used in this tutorial. Comparisons are made between this optimization in phase D and the baseline optimization performed in phase B.

This is the third phase in a 3-phase tutorial series.

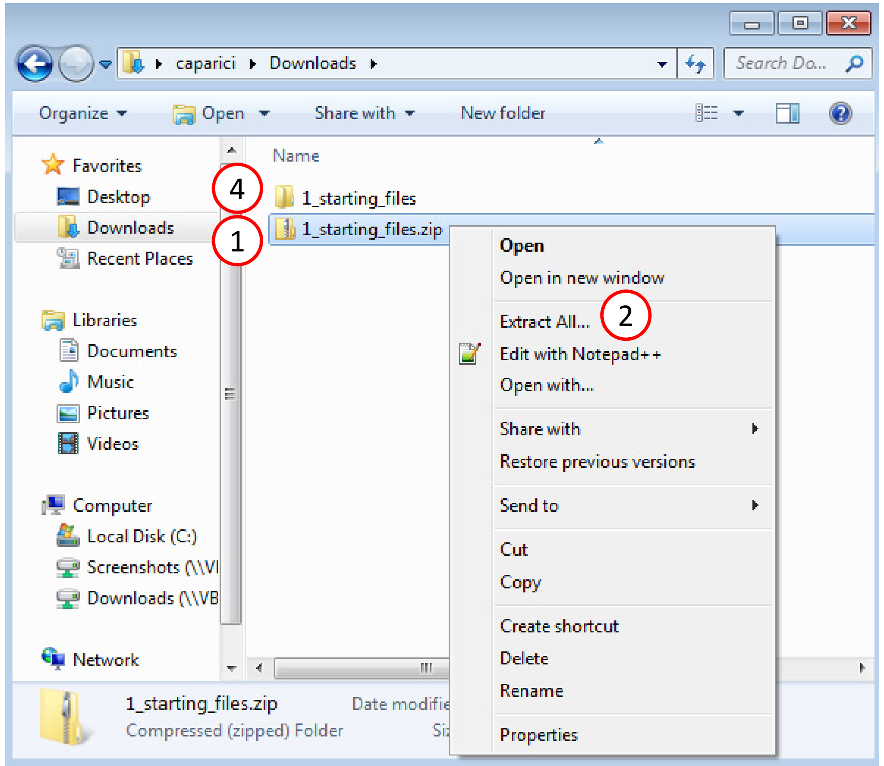
Starting BDF Files: Link 2
Solution BDF Files: Link

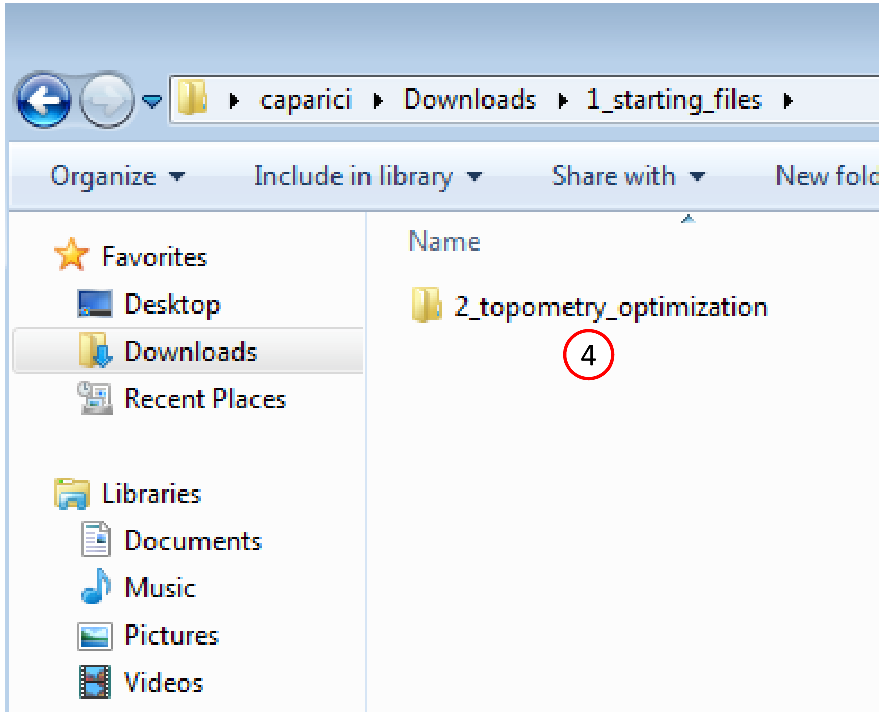


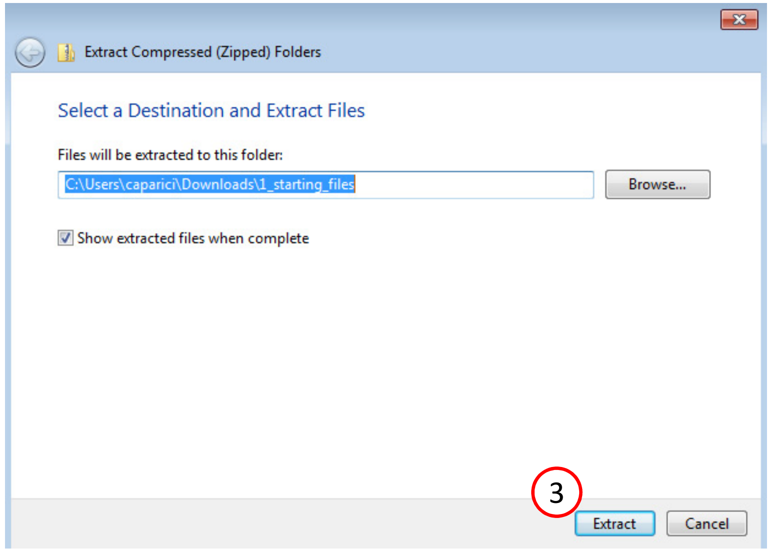
Obtain Starting Files

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.







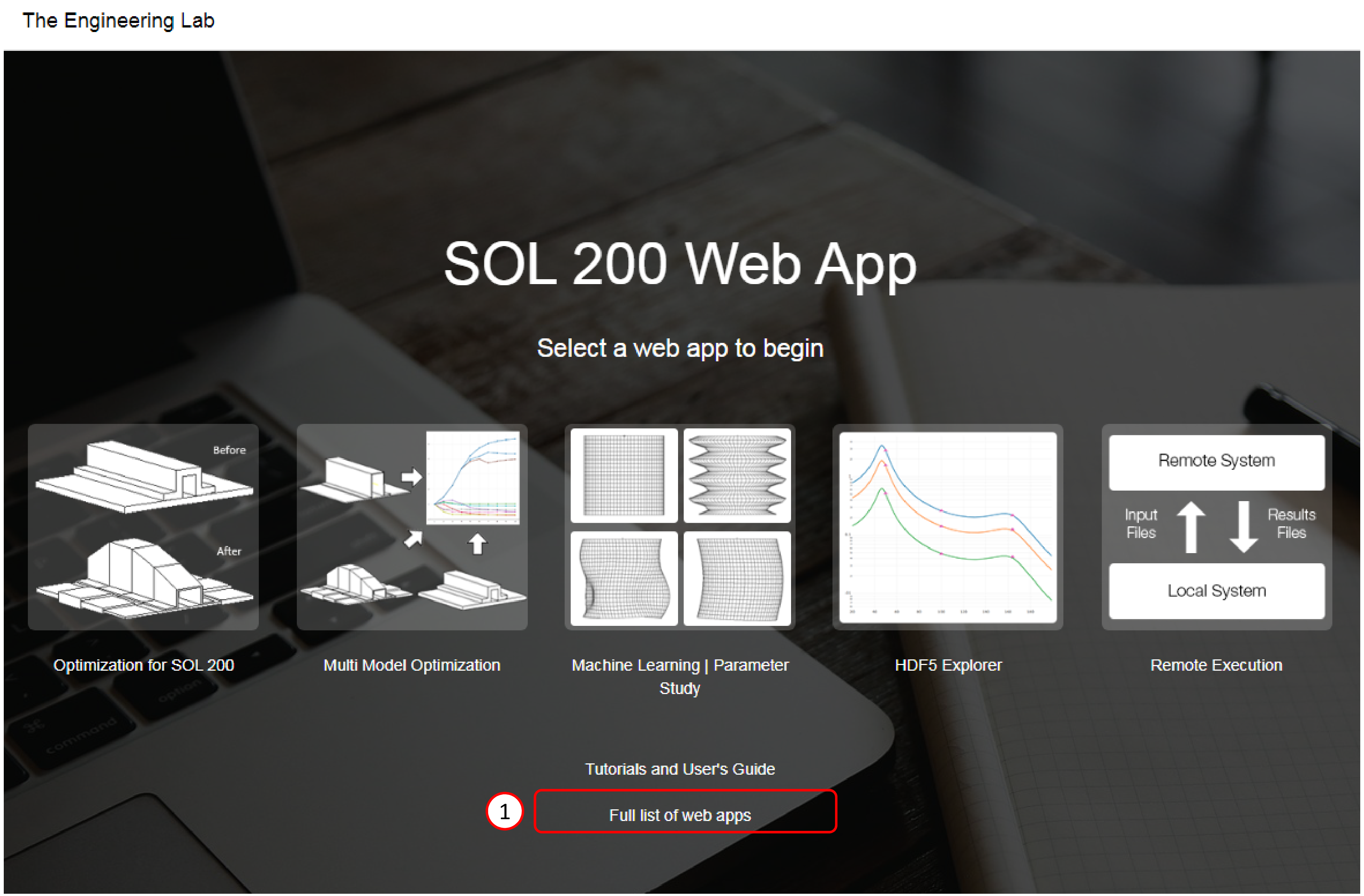
Questions? Email: christian@ the-engineering-lab.com

HEXAGON Technology Partner

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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Import BDF Files

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

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Import PLY000i Files

1. Click Topometry
2. Click Select files
3. Navigate to directory 3_manual_ply000i_files
4. Select the indicated files
5. Click Open
6. Click Upload files

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Create Ply Shape Candidates

1. Click Ply Shapes
2. Click the plus (icon) 3 times to create 3 ply shape candidates
3. Move the 3 sliders to values in the range between 2.3 and 3.0, e.g. 2.5222 and 2.34

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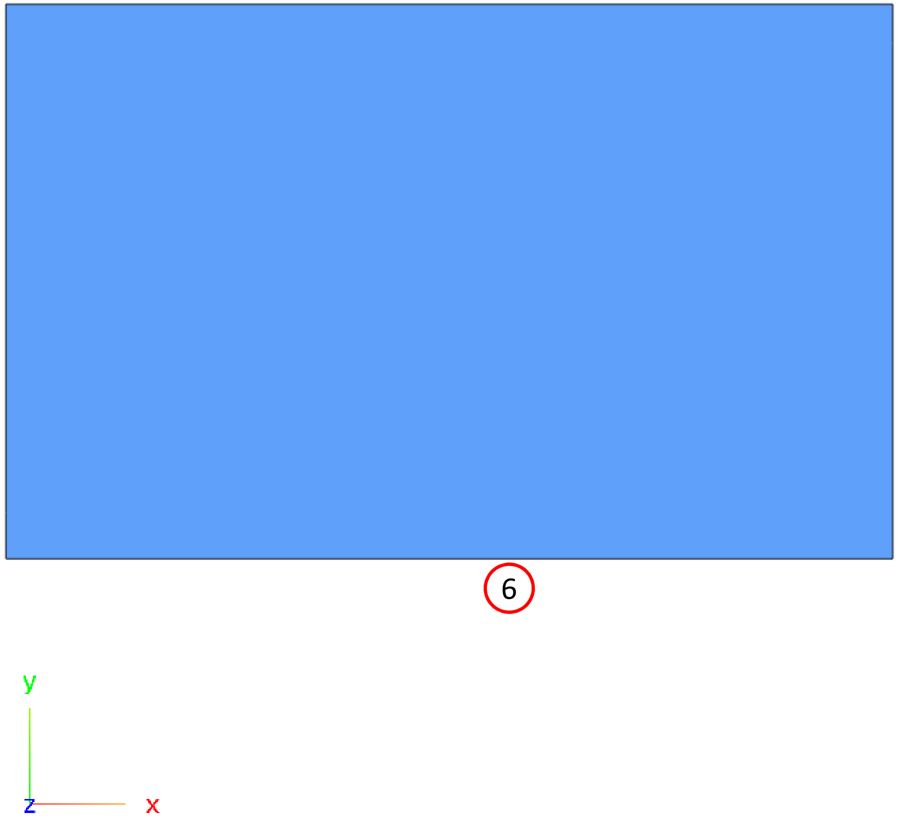
Position the Model

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



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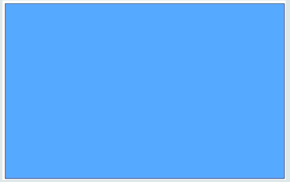
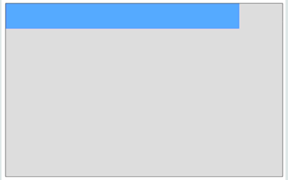
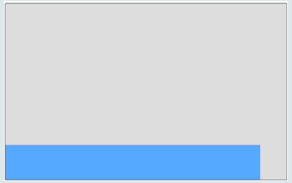
Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

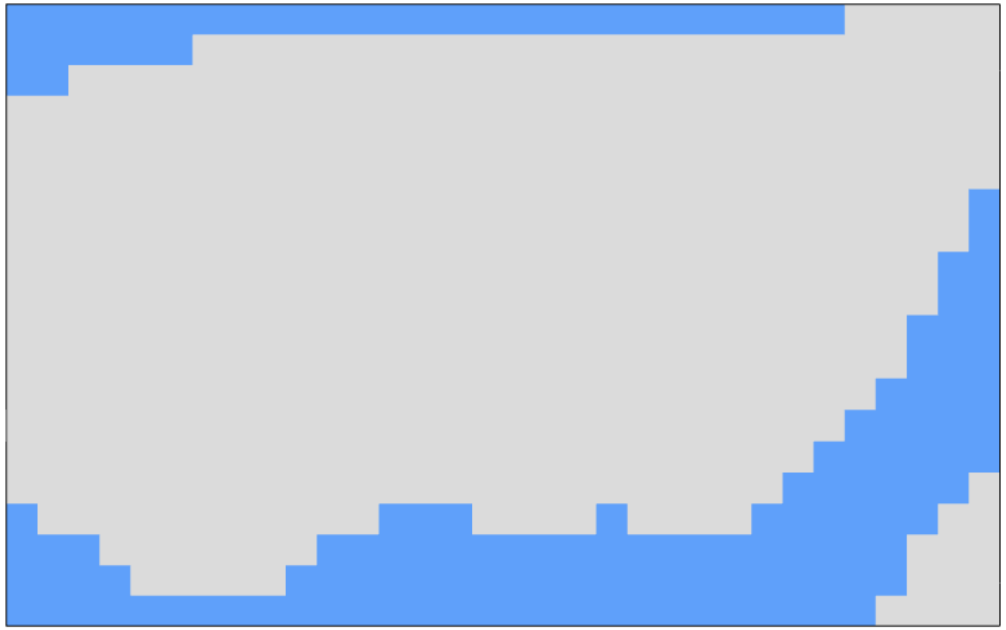
Ply Shape

1

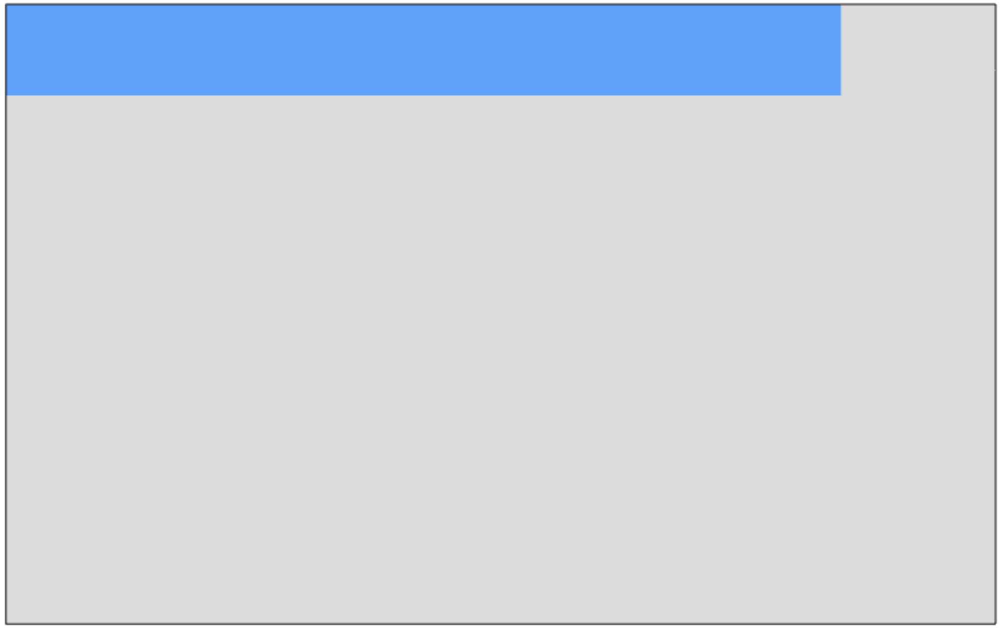
Layer, Theta	Ply Shape Candidate 1 (Not used)	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 0° (Core)	151000, 2151000 	152000, 2152000 	153000, 2153000 	154000, 2154000 	185000, 2185000

Ply Shape Editing: Candidate 2 for 0° (Core)

Before



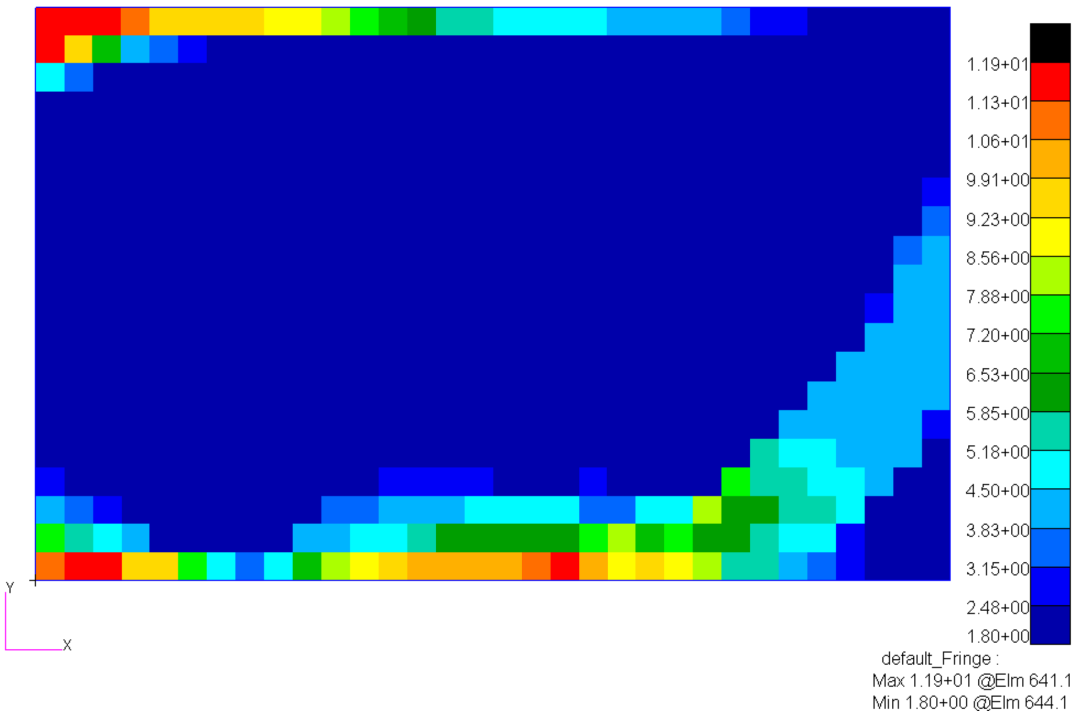
After



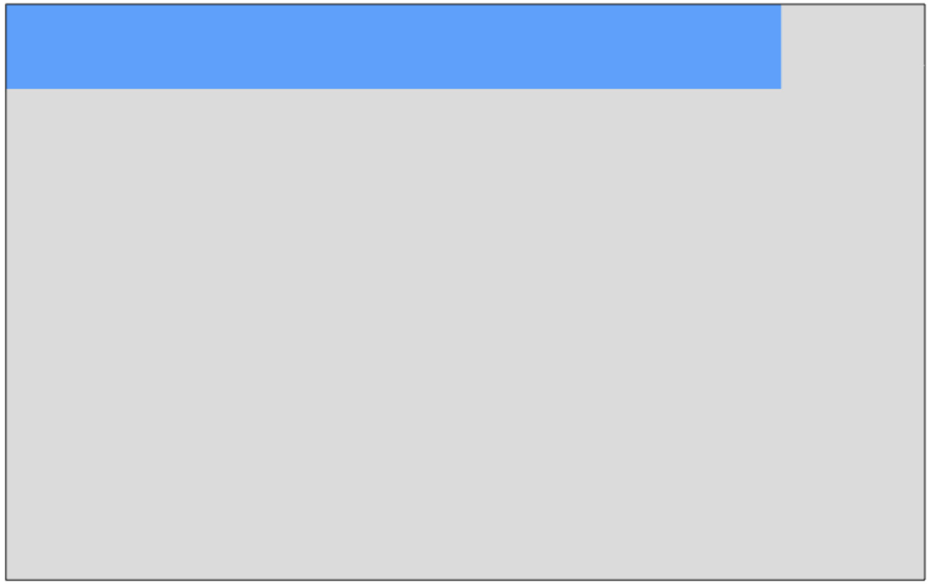
Ply Shape Editing: Candidate 2 for 0° (Core)

- The ply shape candidate takes a form that aligns with the contour of thickness results form a topometry optimization

Thickness Results From Topometry Optimization



Ply Shape Candidate 2



Ply Shape Editing: Candidate 2 for 0° (Core)

1. Click the indicated icon
2. A red sphere appears. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.

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Ply Shape Editing: Candidate 2 for 0° (Core)

1. Click the indicated icon
2. A yellow sphere appears. Press and hold the left mouse button, and drag the sphere to add the ply from the indicated region.

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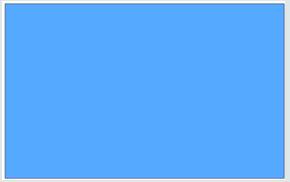
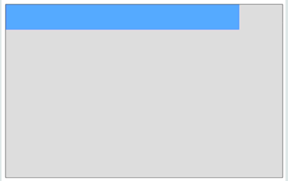
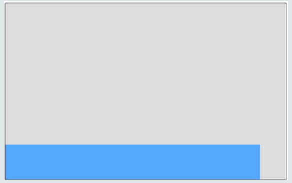
Ply Shape

1

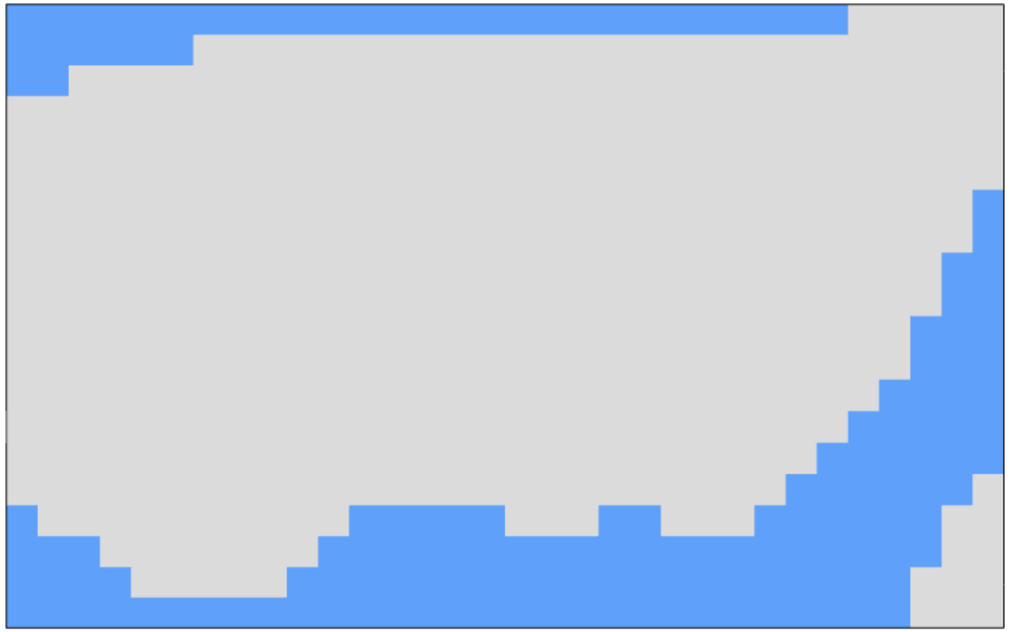
Layer, Theta	Ply Shape Candidate 1 (Not used)	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 0° (Core)	151000, 2151000 	152000, 2152000 	153000, 2153000 	154000, 2154000 	185000, 2185000

Ply Shape Candidates Creation

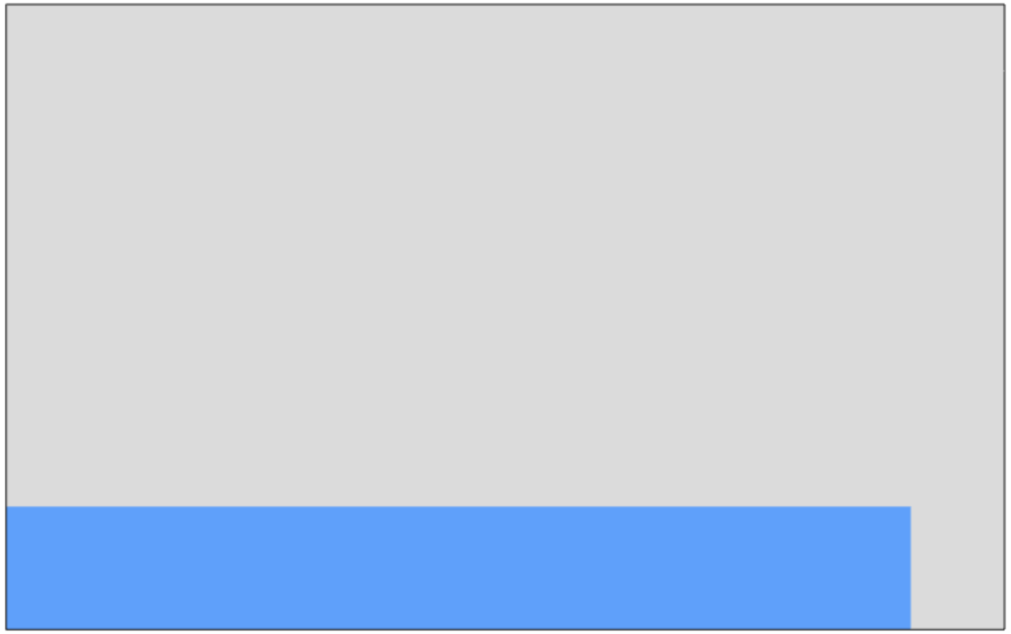
1. The indicated ply shape candidates will be created

Ply Shape Editing: Candidate 3 for 0° (Core)

Before



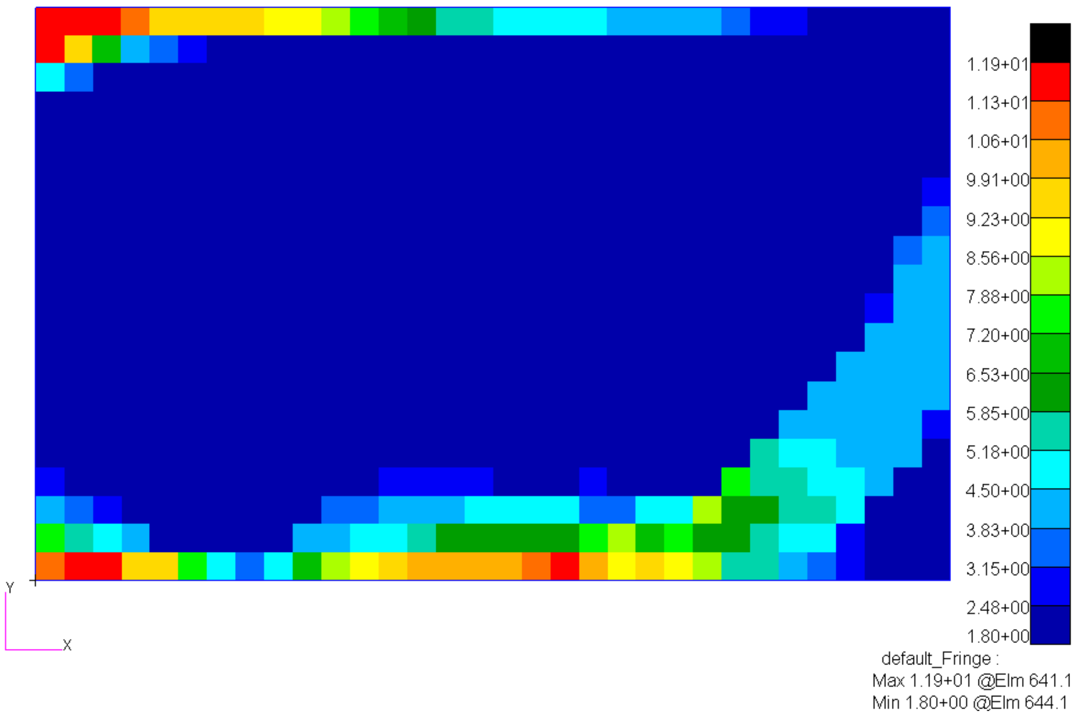
After



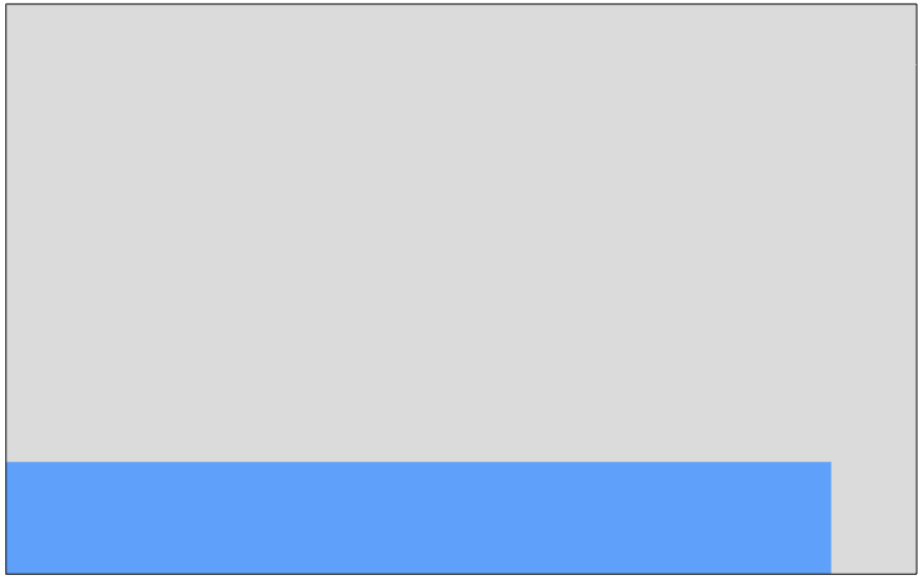
Ply Shape Editing: Candidate 3 for 0° (Core)

- The ply shape candidate takes a form that aligns with the contour of thickness results form a topometry optimization

Thickness Results From Topometry Optimization



Ply Shape Candidate 3



Ply Shape Editing: Candidate 3 for 0° (Core)

1. Click the indicated icon
2. A red sphere appears. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.

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Ply Shape Editing: Candidate 3 for 0° (Core)

1. Click the indicated icon
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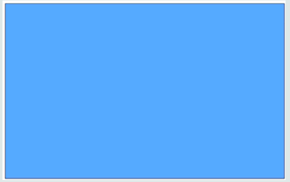
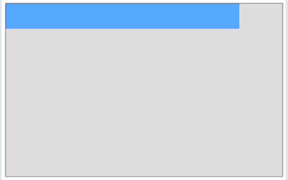
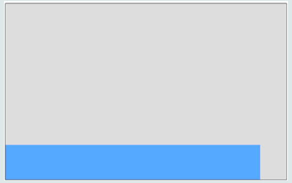
1

Ply Shape

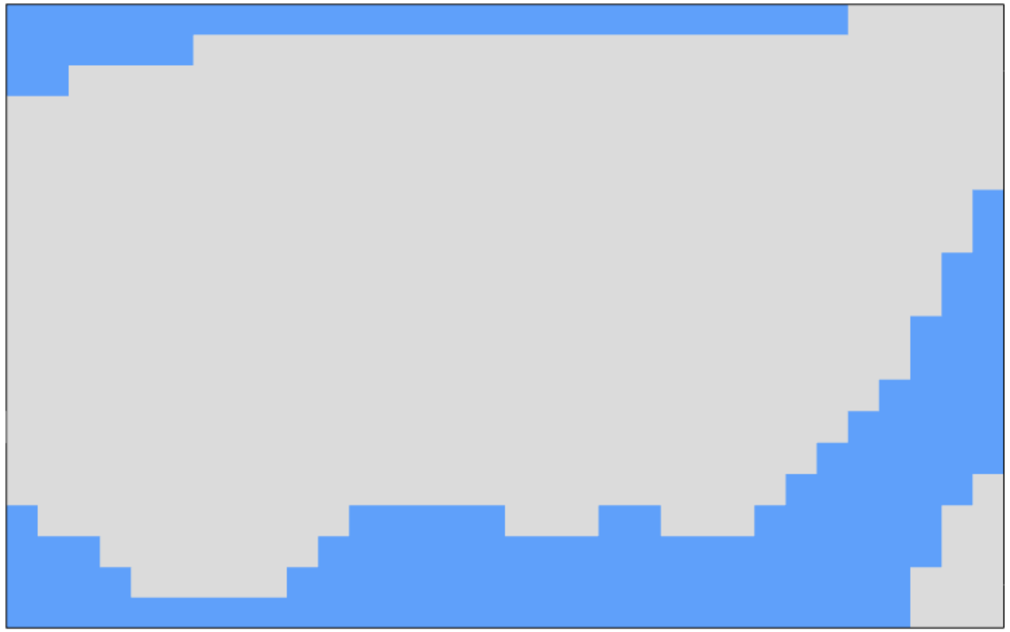
Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

Layer, Theta	Ply Shape Candidate 1 (Not used)	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 0° (Core)	151000, 2151000 	152000, 2152000 	153000, 2153000 	154000, 2154000 	185000, 2185000

Ply Shape Editing: Candidate 4 for 0° (Core)

Before

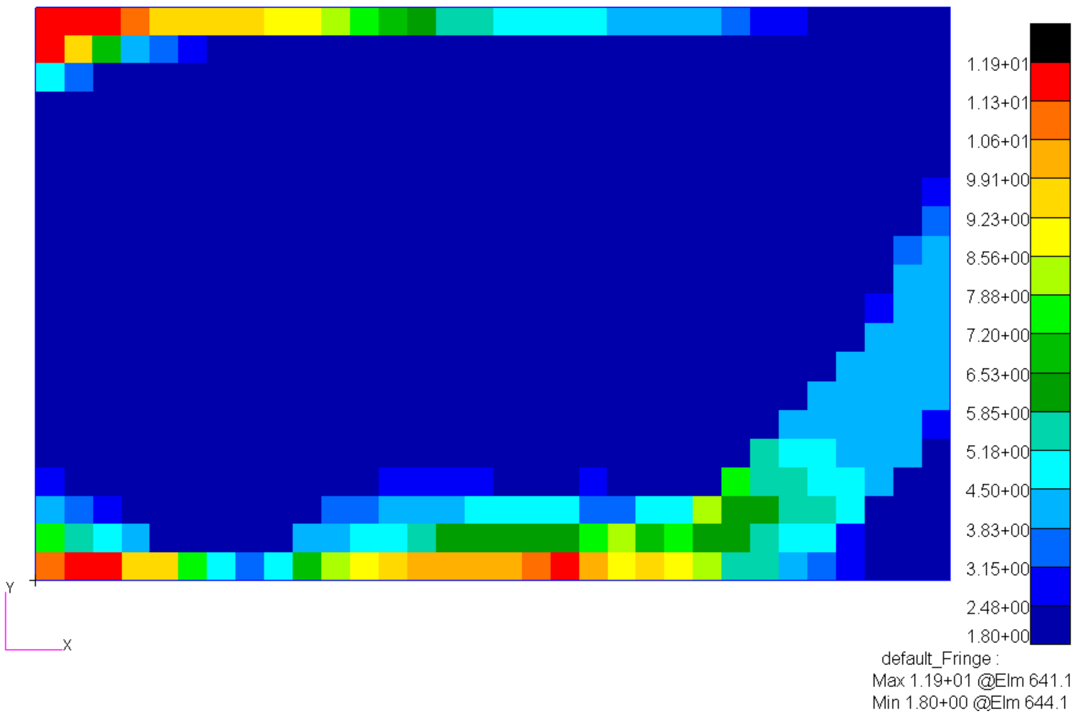


After

Ply Shape Editing: Candidate 4 for 0° (Core)

- The ply shape candidate takes a form that aligns with the contour of thickness results form a topometry optimization

Thickness Results From Topometry Optimization



Ply Shape Candidate 4

Ply Shape Editing: Candidate 4 for 0° (Core)

1. Click the indicated icon
2. A red sphere appears. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.

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the-engineering-lab.com

or contact

christian@ the-engineering-lab.com

Ply Shape Editing: Candidate 4 for 0° (Core)

1. Click the indicated icon
2. A yellow sphere appears. Press and hold the left mouse button, and drag the sphere to add the ply from the indicated region.

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Ply Shape Consolidation

1. Click View PCOMPG Zones
2. Notice the stack has the core layer twice. This is not desired, each zone should have only one core layer.

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

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Ply Shape Consolidation

1. Click +Options
2. Click Enable Checkboxes – Included in PCOMPGs
3. Unmark the indicated checkbox for GPLY 151000. This action removes a continuous core layer that spanned the entire model and all PCOMPG zones.
4. Now the zones have at most one core layer
5. The PCOMPG 2 zone no longer has a core layer and will be address in the next page

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

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Ply Shape Consolidation

1. Click Add Complement Core
2. A new core layer has been created that spans only PCOMPG 3
3. Now each zone has one core layer

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

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Ply Shape Consolidation

1. Mark the indicated checkbox. The newest core layer is displayed.

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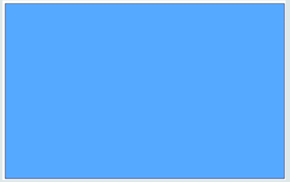
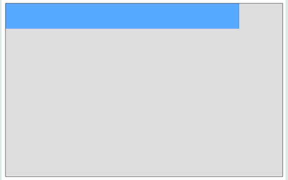
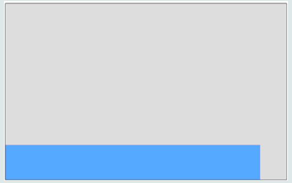
Ply Shape

Ply Shape Candidates Creation

1. So far, ply shape candidates 2, 3, 4 and 5 have been created

Layer, Theta	Ply Shape Candidate 1 (Not used)	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 0° (Core)	151000, 2151000 	152000, 2152000 	153000, 2153000 	154000, 2154000 	185000, 2185000 

Ply Shape Consolidation

1. If any PCOMPG zones have more than one core layer, this is not desired and the previous steps should be revisited and the created core shapes should be corrected.

2. In this example, a core shape overlaps the adjacent core shape which causes PCOMPG 5 to have 2 core layers. This is not desired and should be corrected.

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Confirm Ply Number Optimization Configuration

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

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Consider Additional Optimization Options

1. Scroll to section Additional Optimization Options
2. Set Z0 Offset Relationship to Above
3. Using Above will set Z0=0.0 in the PCOMPG entries.
    - If Below is used, DVPREL2 entries for Z0 are created to impose the correct offset. If blank is used, Z0 is assumed to be -T/2, where T is the total thickness of the composite.

Refer to the appendix for more information about these options.

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Save New Entries

1. Navigate to section Respective PCOMP/PCOMPG Entries
2. The newest entries are displayed. There are approximately 4 new PCOMPG entries (PCOMPG 2-5) and multiple SOL 200 entries (DESVAR, DVPREL1, etc.)
3. Click Save New Entries
4. A checkbox confirm the entries has been saved.

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

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Save New Entries

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

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Download

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

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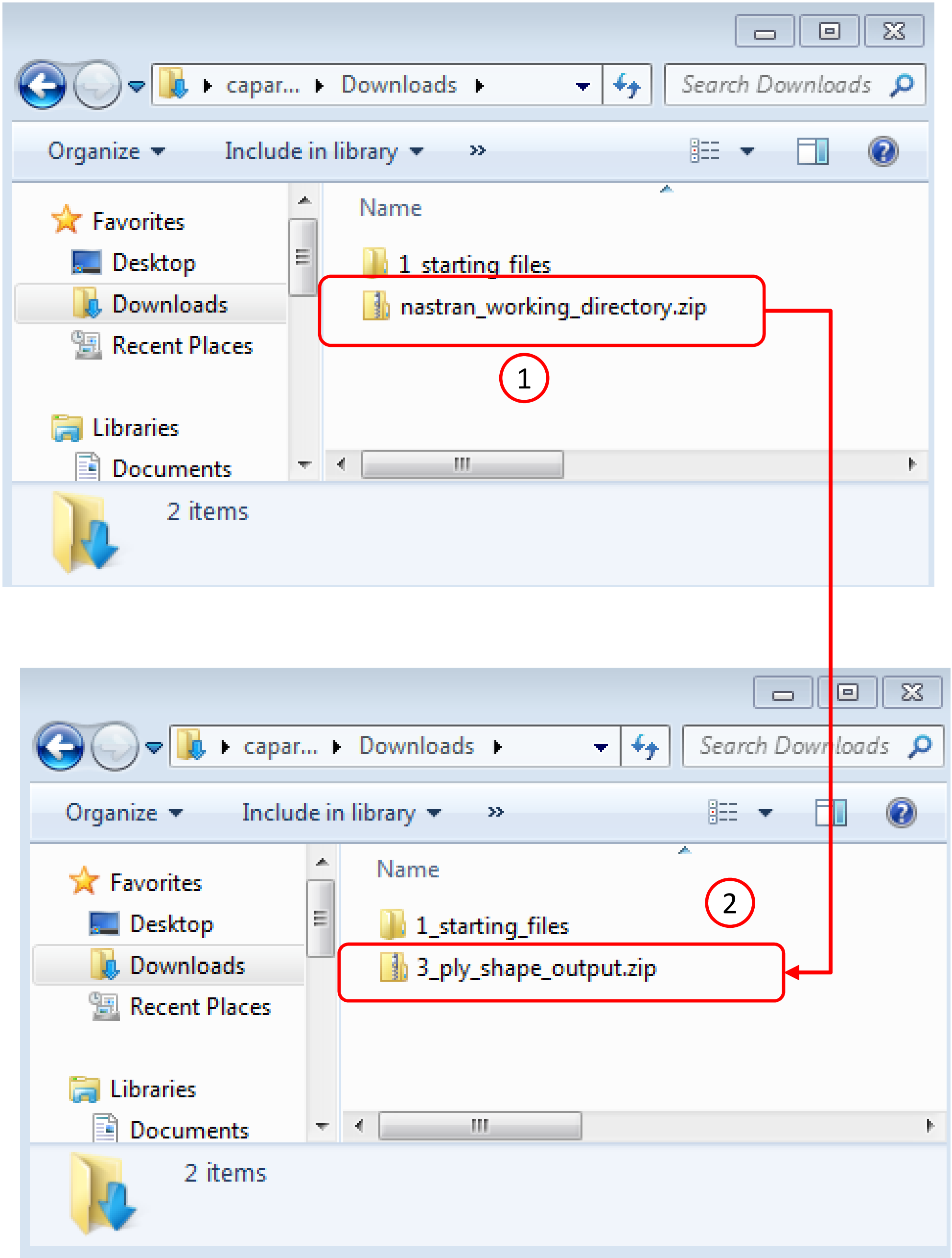
Rename ZIP File

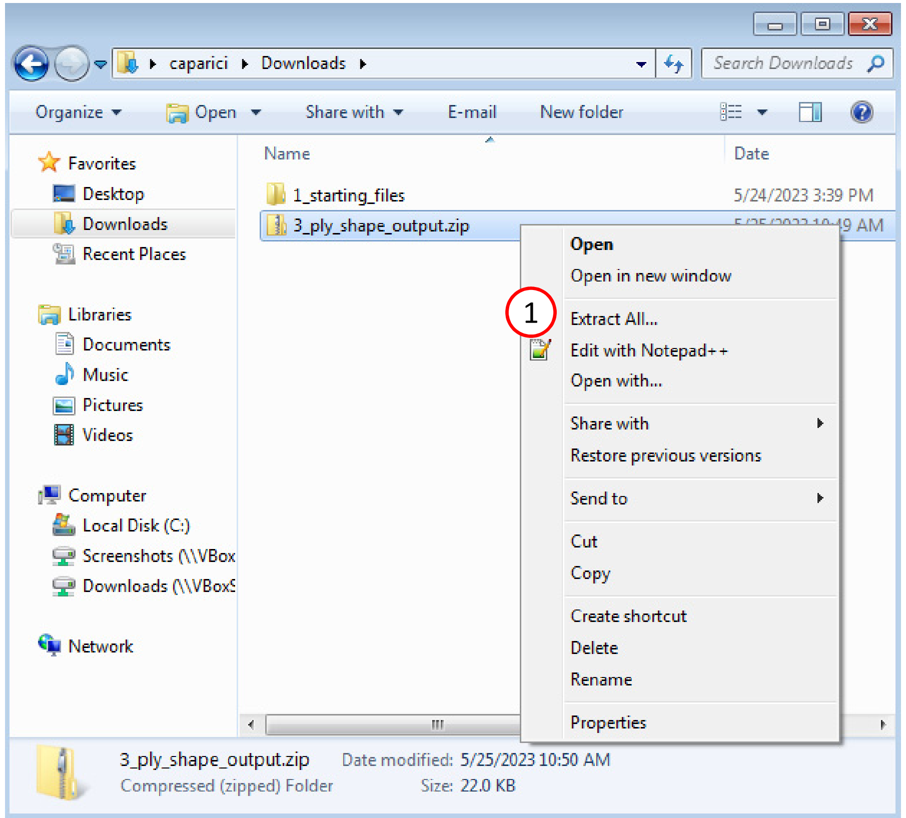
1. A new ZIP file has been downloaded
2. Rename the downloaded ZIP file to 3_ply_shape_output.zip

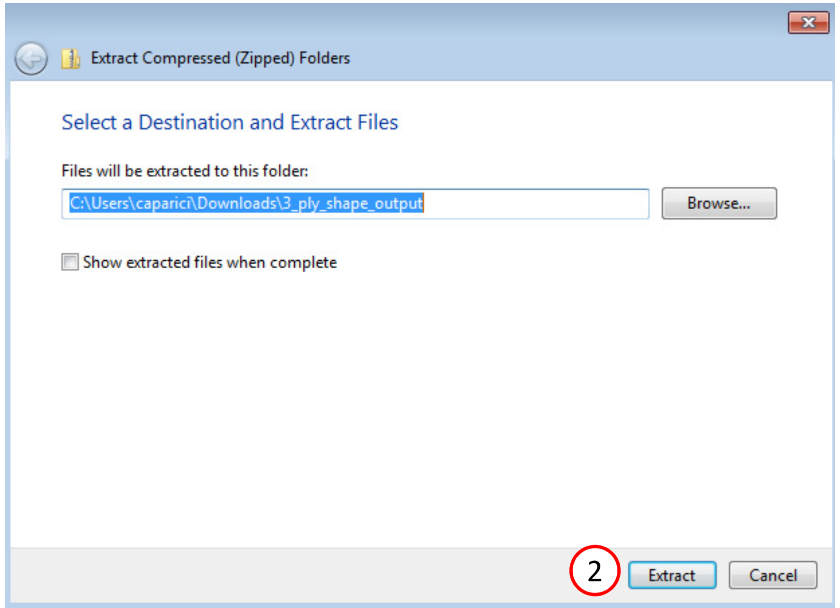


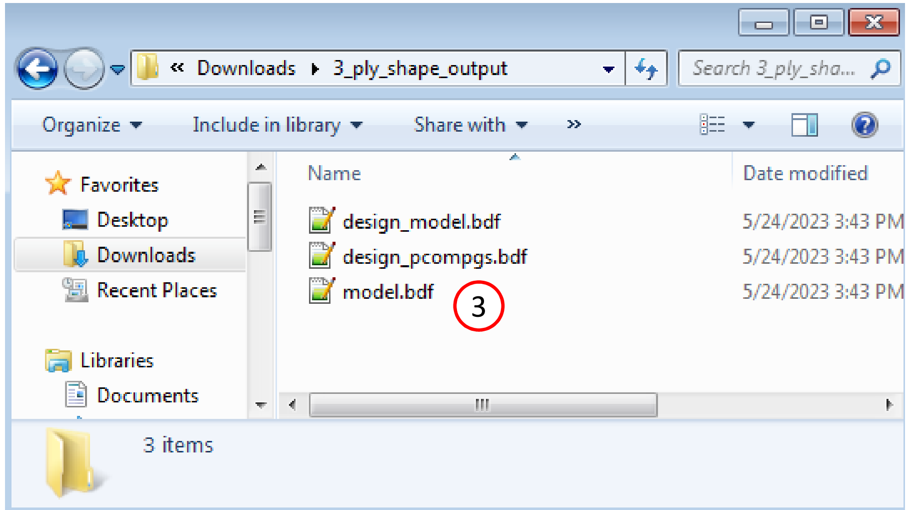
Part 2 – Core Thickness Optimization

Extract the ZIP File

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

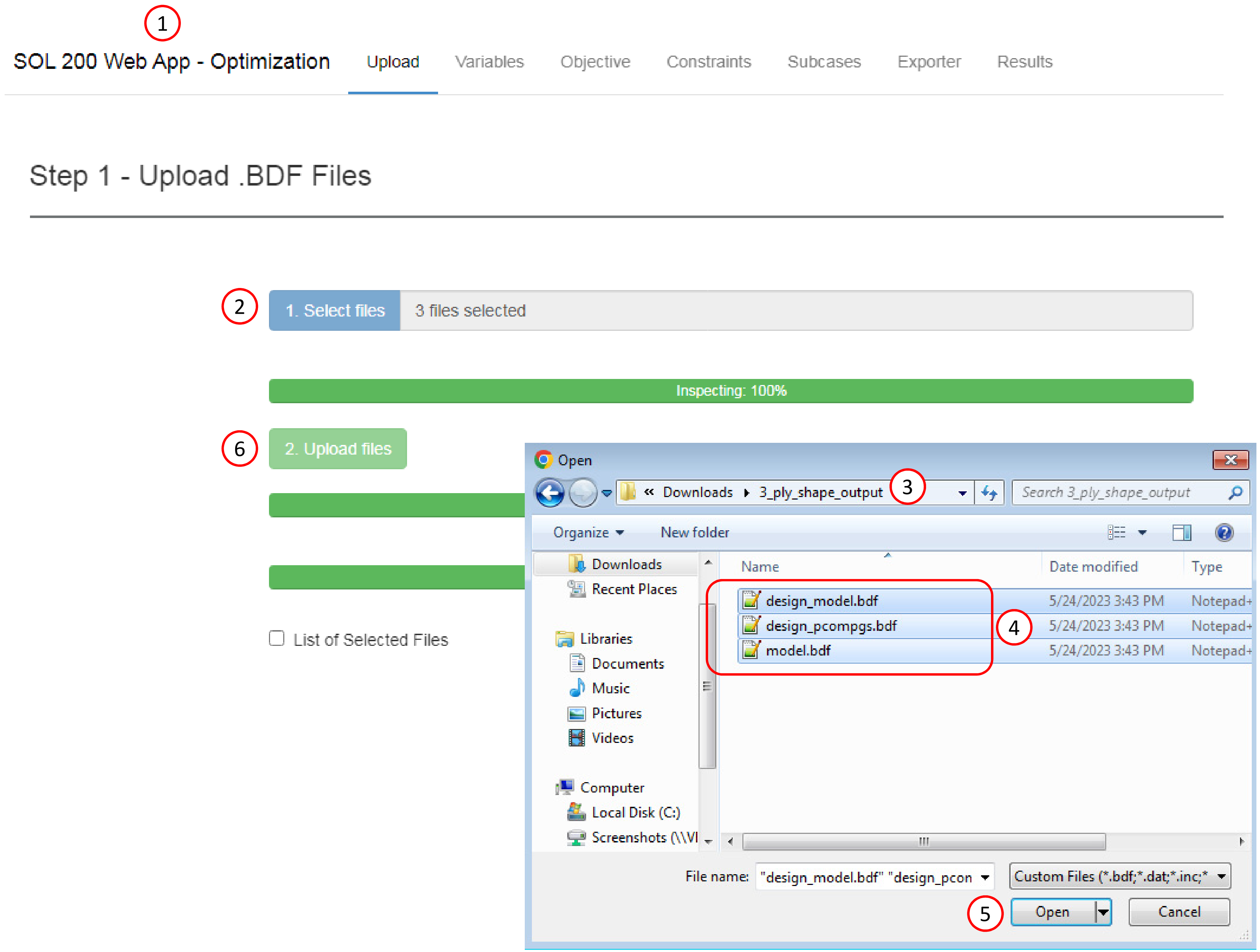






Upload BDF Files

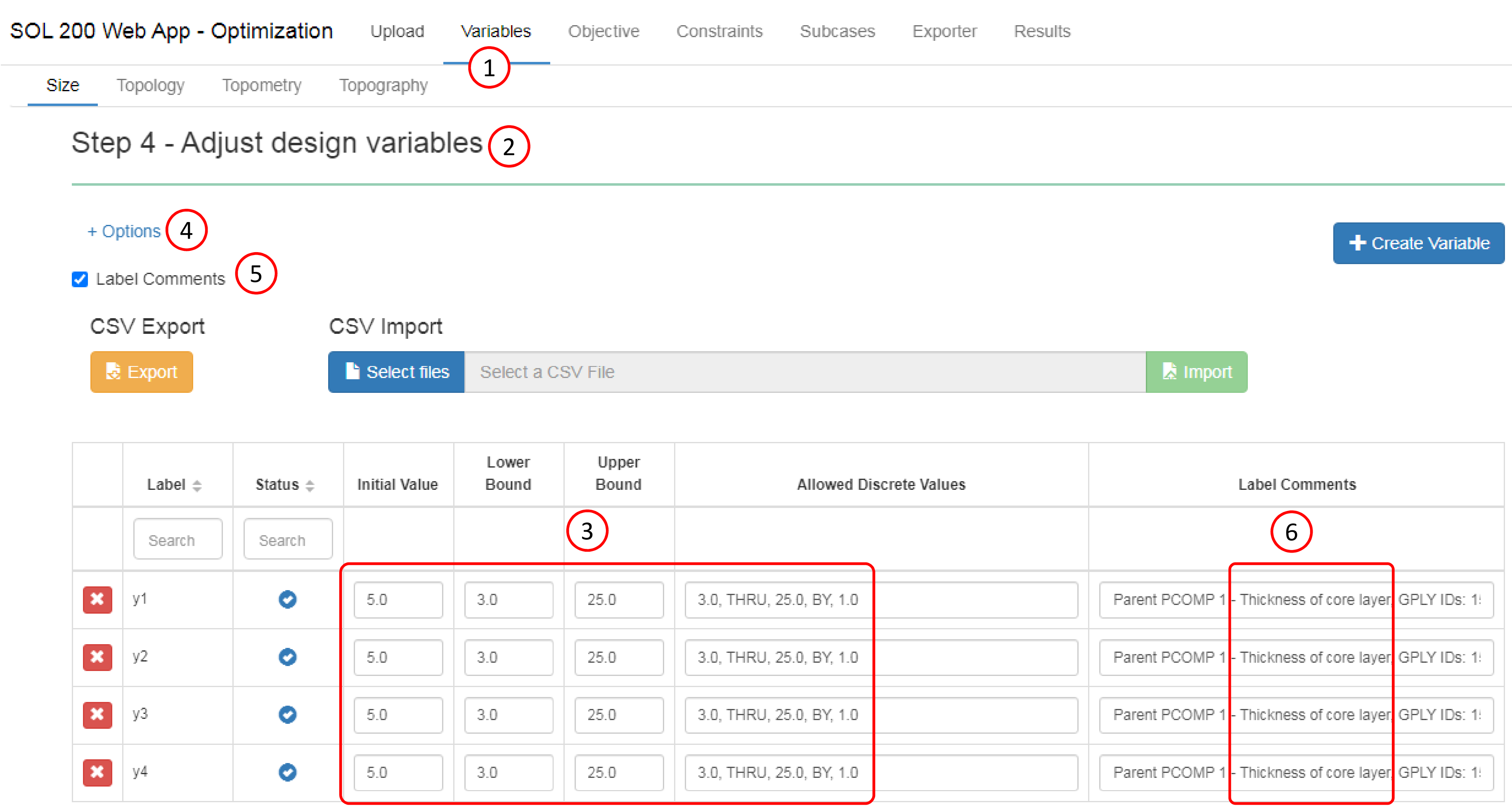
1. Switch to the Optimization web app
2. Click Select files
3. Navigate to directory 3_ply_shape_output
4. Select the indicated files
5. Click Open
6. Click Upload files



Variables

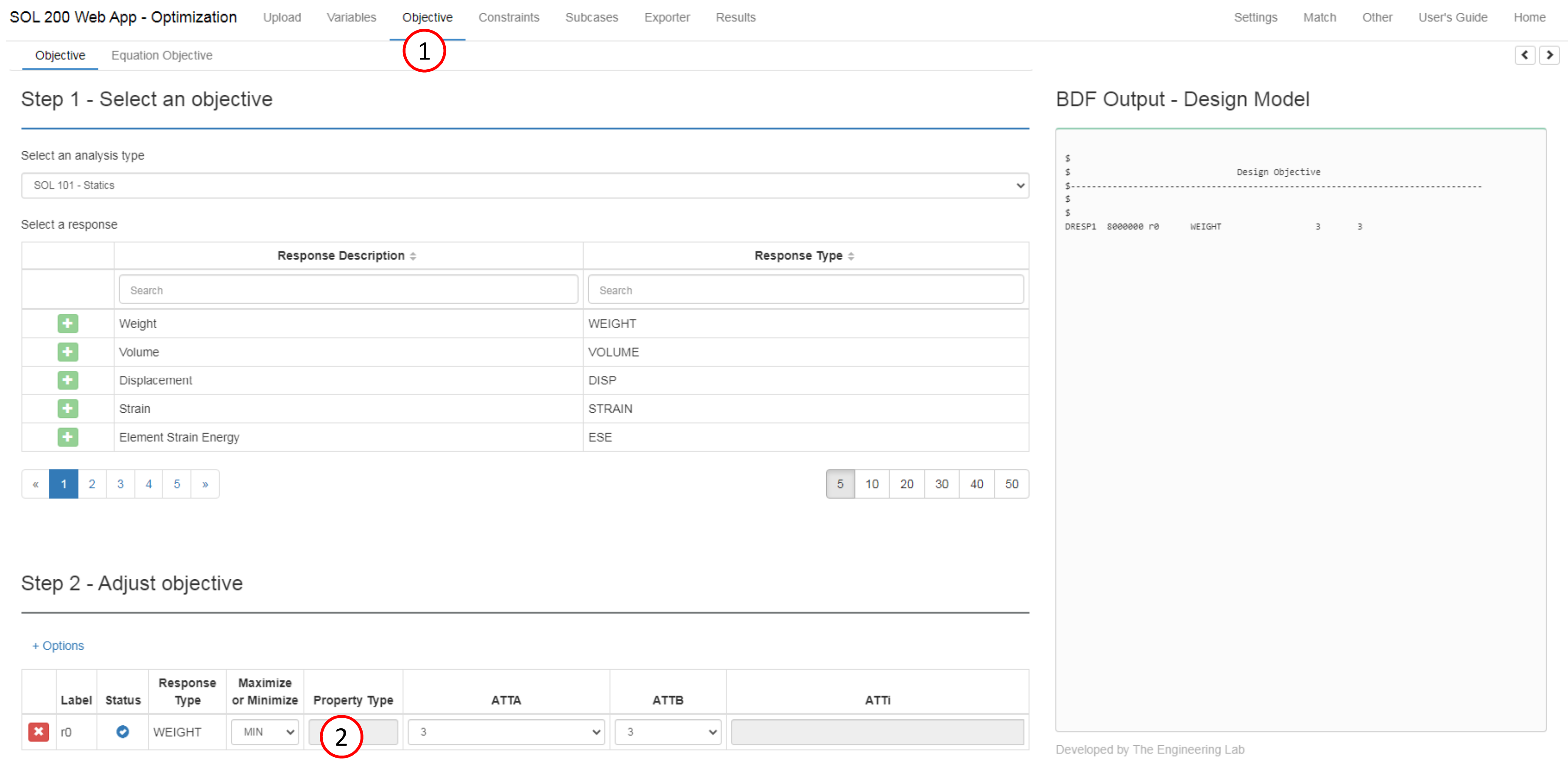
1. Click Variables
2. Navigate to section Step 4 – Adjust design variables
3. Make the following changes to the variables
   - Initial Value: 5.0
   - Lower Bound: 3.0
   - Upper Bound: 25.0
   - Allowed Discrete Values: 3.0, THRU, 25.0, BY, 1.0
4. Click +Options
5. Mark the checkbox for Label Comments
6. Update the label to partly read: Thickness of core layer

- The previous design variables were configured to be ply number variables. In this step, the initial value, bounds and allowed values are in terms of thickness.



Objective

1. Click Objective
2. The weight is already set as an objective

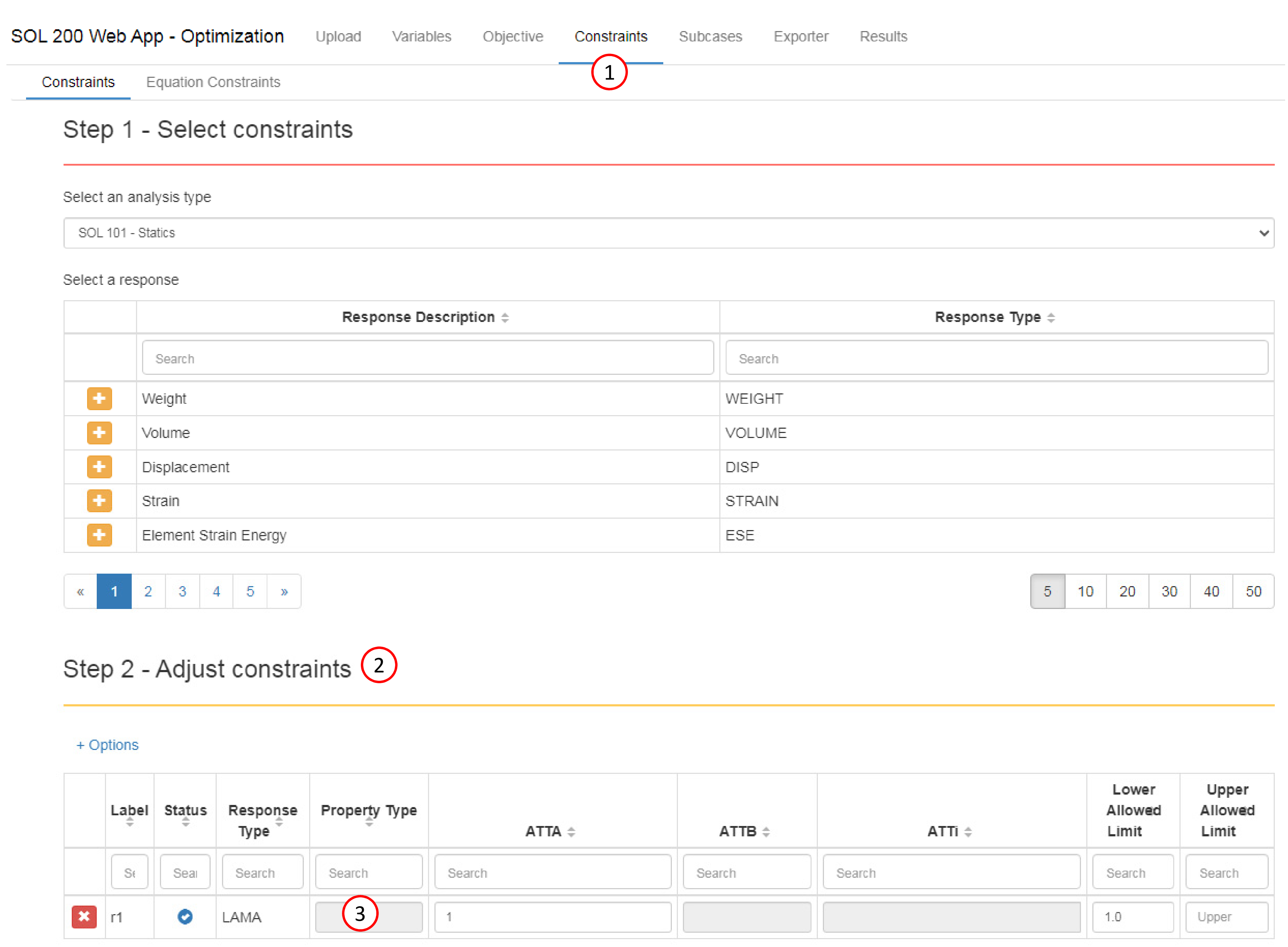


- The objective was previously defined in the BDF files when the TOMVAR entries were defined. The weight objective is left as is.

Constraints

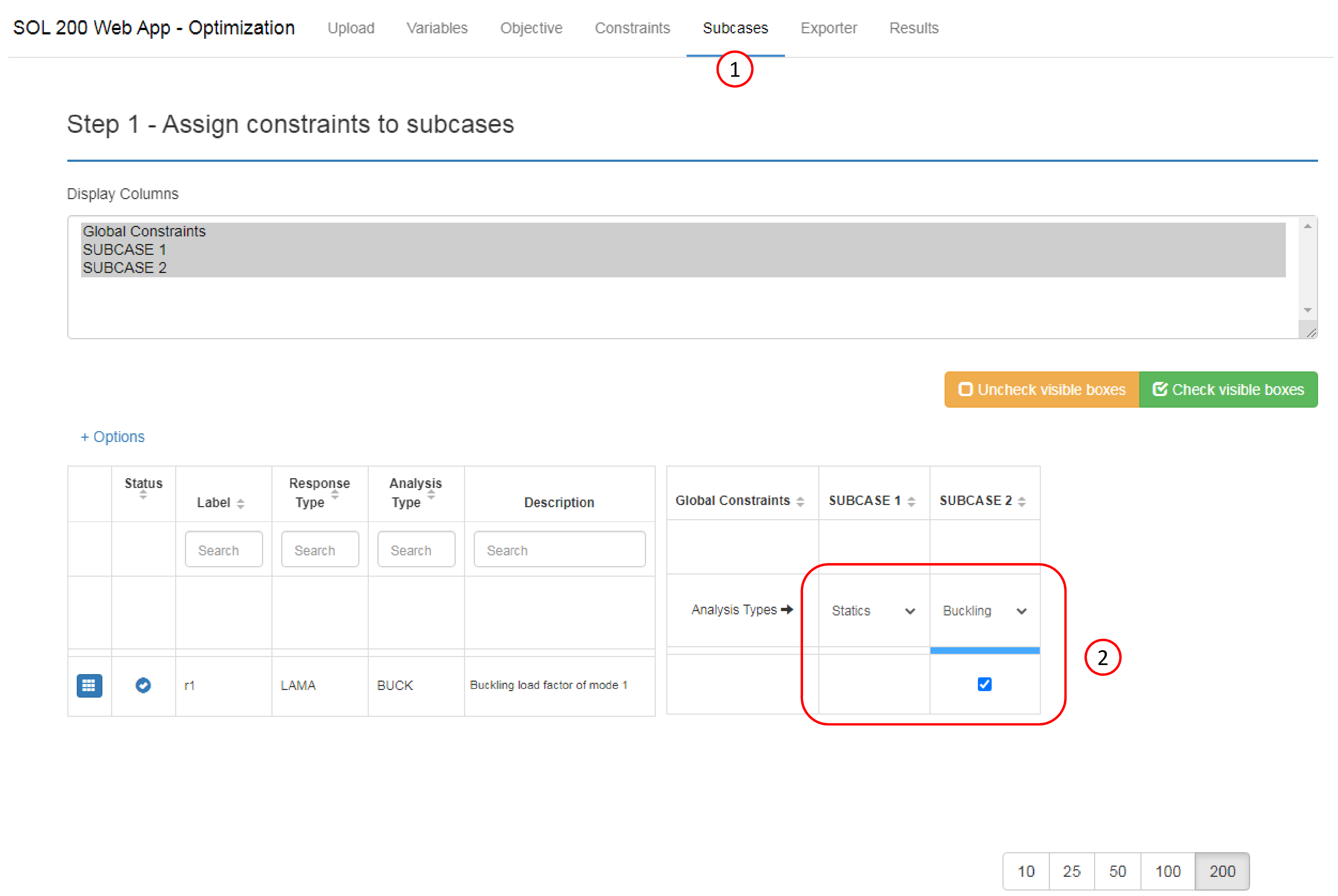
1. Click Constraints
2. Navigate to section Step 2 – Adjust constraints
3. Ensure the constraint on buckling load factor is present

- Recall the constraint on buckling load factor was created during the topometry optimization and is carried over in the BDF files until now



Subcases

1. Click Subcases
2. Ensure the following is configured
    - Subcase 1
        - Analysis: Statics
    - Subcase 2
        - Analysis: Buckling
        - Constraint r1 is assigned to subcase 2



Settings

1. Click Settings
2. Set the maximum number of design cycles to 20
3. Ensure the trust region setting is set to 1 – Trust Region On

SOL 200 Web App - Optimization Upload Variables Objective Constraints Subcases Exporter Results Settings Match Other User's Guide Home

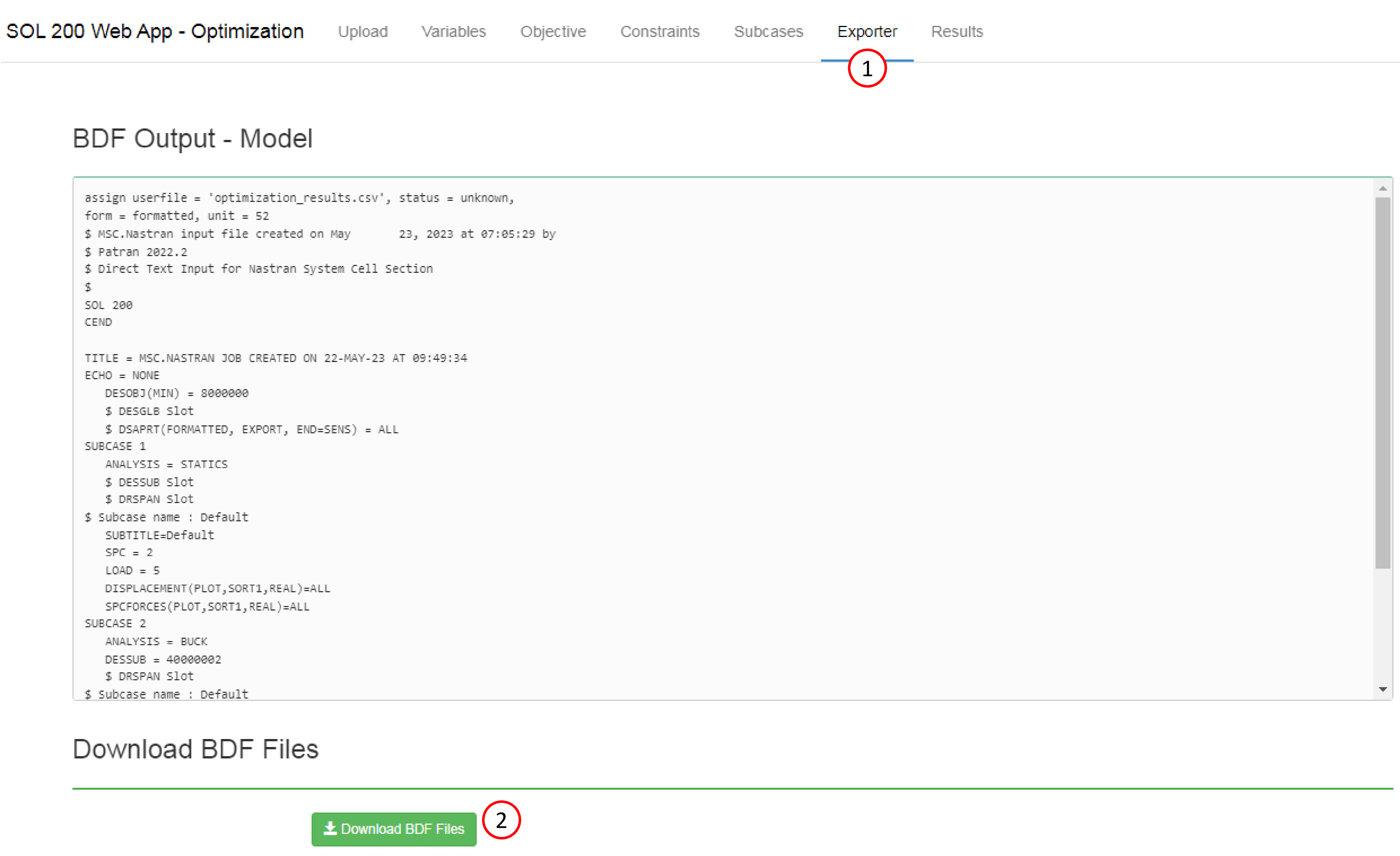
Optimization Settings

Parameter	Description	Configure
APRCOD	Approximation method to be used	☐ 2 - Mixed Method
CONV1	Relative criterion to detect convergence	☐ Enter a positive real number
CONV2	Absolute criterion to detect convergence	☐ Enter a positive real number
DELX	Fractional change allowed in each design variable during any optimization cycle	☐ Enter a positive real number
DESMAX	Maximum number of design cycles to be performed	☑ 20
DISBEG	Design cycle number for discrete variable processing initiation	☐ Enter a positive integer
GMAX	Maximum constraint violation allowed at the converged optimum	☐ Enter a positive real number
P1	Print items, e.g. objective, design variables, at every n-th design cycle to the .f06 file	☑ 1
P2	Items to be printed to the .f06 file	☑ 12 - Print constraints and respons
TCHECK	Topology Checkerboarding	☐ -1 - Automatic selection (Default)
TDMIN	Minimum diameter of members in topology optimization	☐ Enter a positive real number
TREGION	Trust Region	☑ 1 - Trust Region On

Export New BDF Files

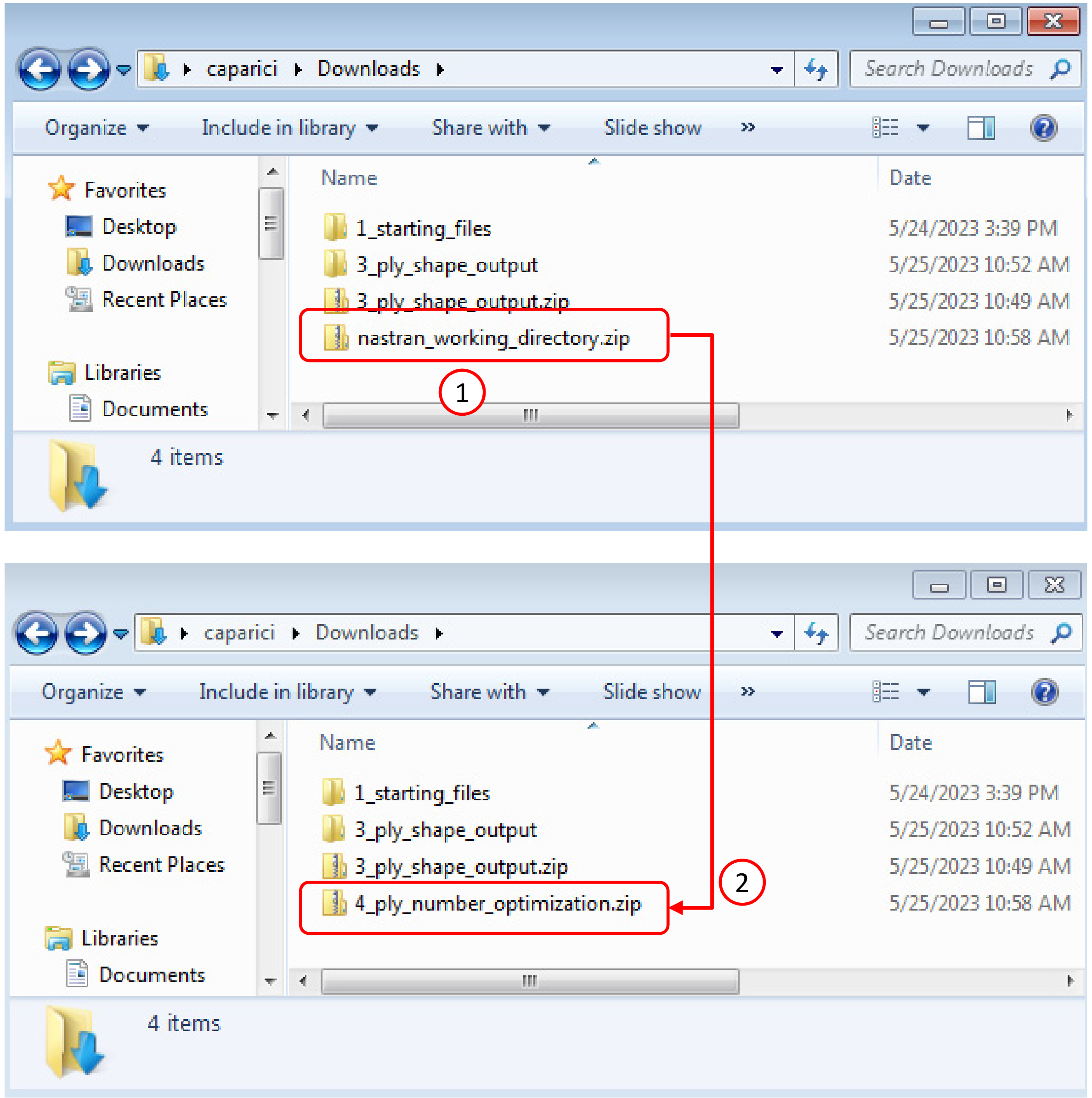
1. Click on Exporter
2. Click on Download BDF Files

- 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”



Rename ZIP File

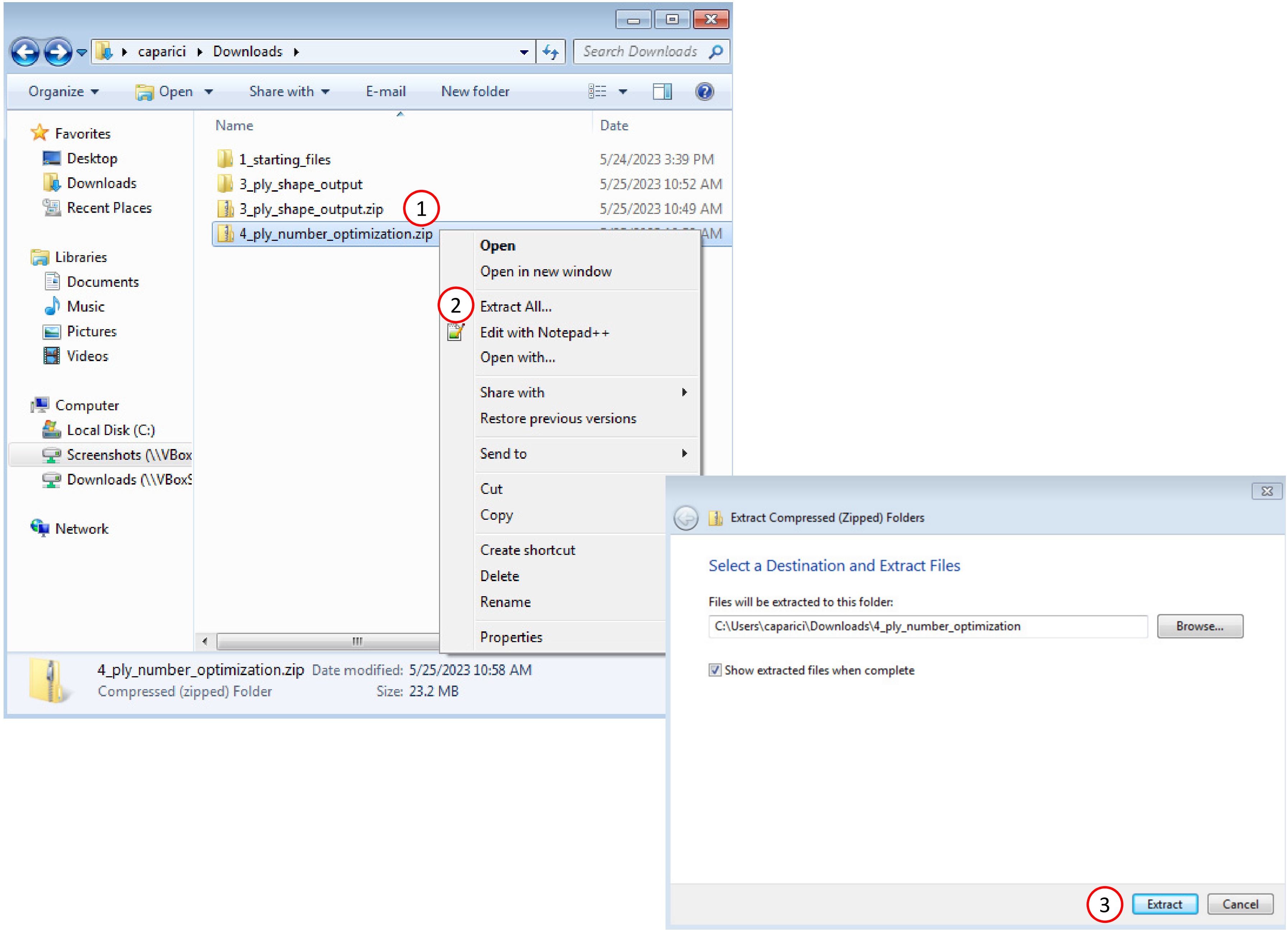
1. A new ZIP file has been downloaded
2. Rename the downloaded ZIP file to 4_ply_number_optimization.zip



Perform the Optimization with Nastran SOL 200

1. A new .zip file has been downloaded
2. Right click on the file and click Extract All
3. 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

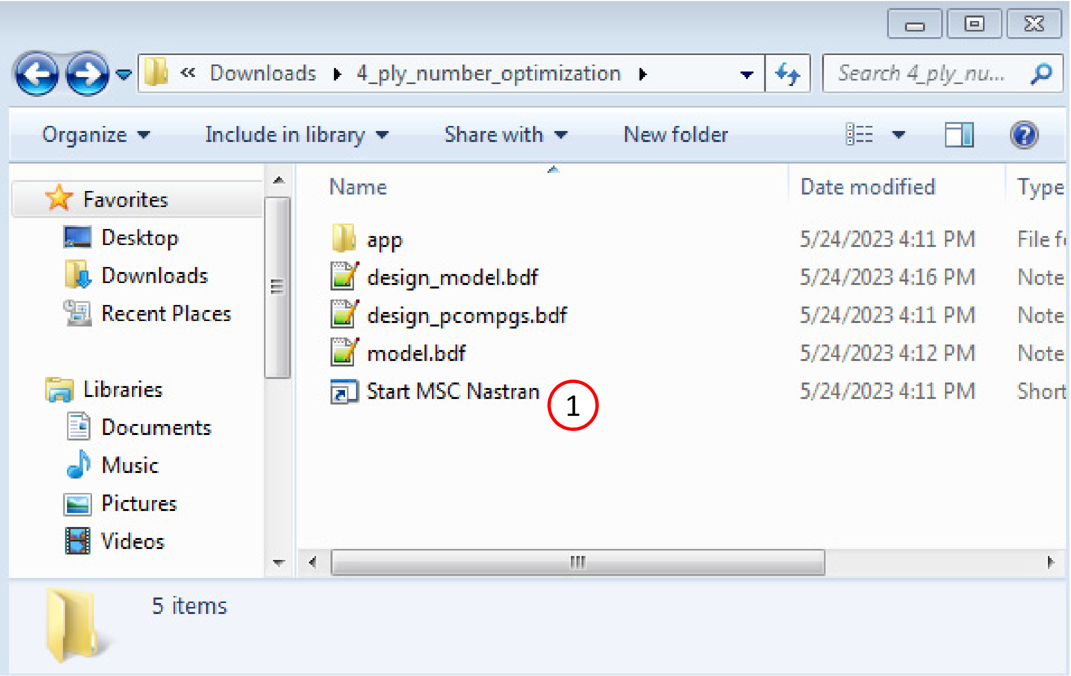
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the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

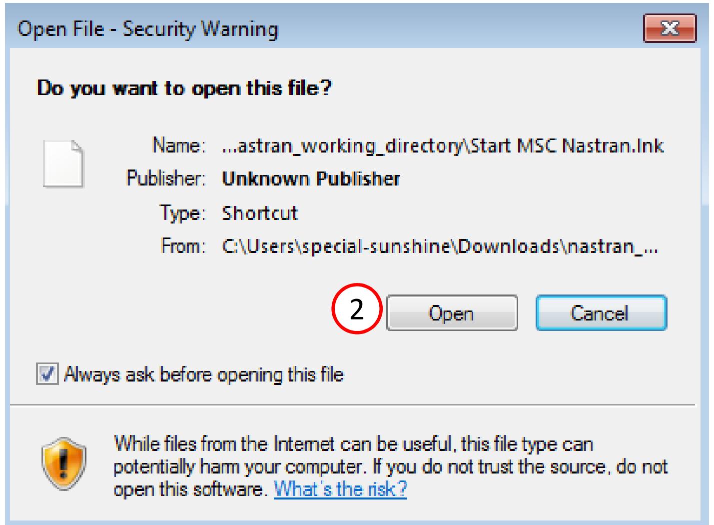
Using Linux?

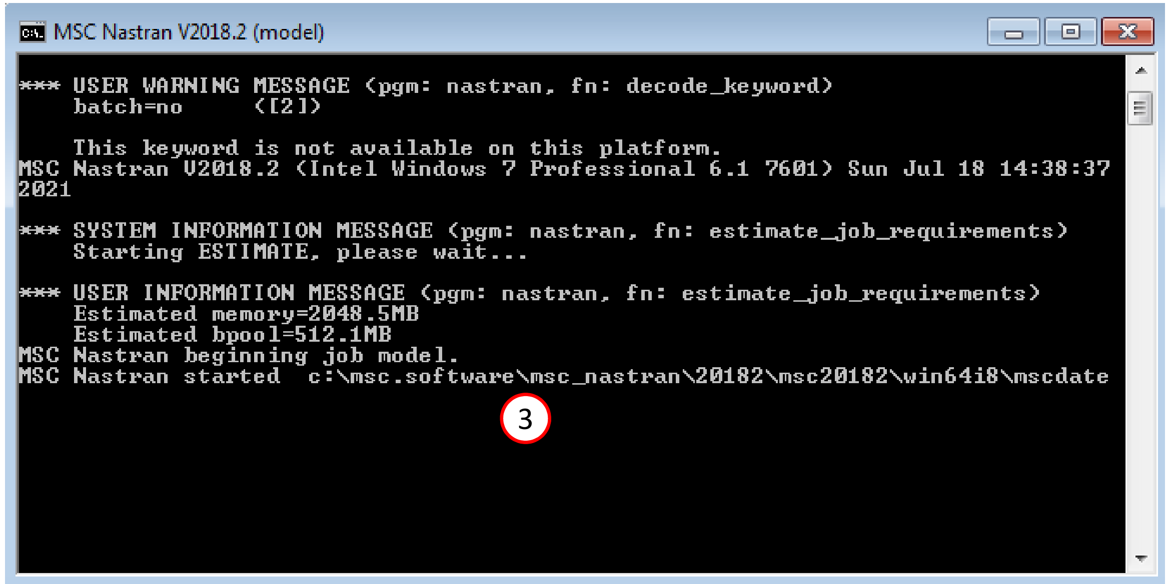
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
    cd ./nastran_working_directory
3) Use this command to start the process
    ./Start_MSC_Nastran.sh

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.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- Note that the optimization solutions is sensitive to different system configurations. This optimization yielded an objective of 2.303103E-05 on Windows 7, but on Linux, yielded an objective of 2.305057E-05. Alternatively, the difference in the converged solution may be due to a difference in the surface area of the ply shape candidates. A difference of one 2D element may yield a different solution.
- Normalized constraint values that are positive indicate a design that violates at least one design constraint, and such designs are named infeasible designs. Negative normalized constraint values are desired and indicated the design satisfies all design constraints. Such designs are named feasible designs. The normalized constraint of the final design is negative, indicating a feasible design.

SOL 200 Web App - Local Optimization Results

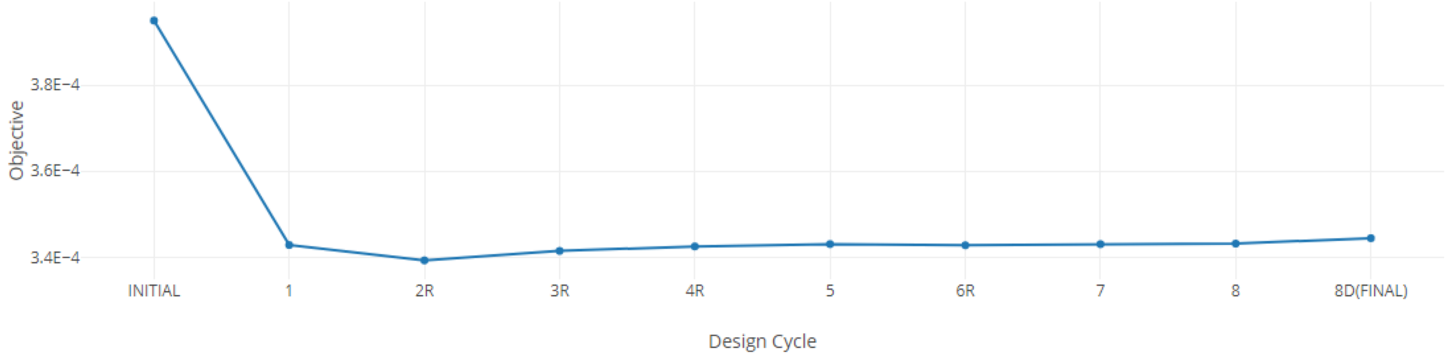
Home

1

Final Message in .f06

```
RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER =       8.
AND HARD FEASIBLE DISCRETE DESIGN OBTAINED
```

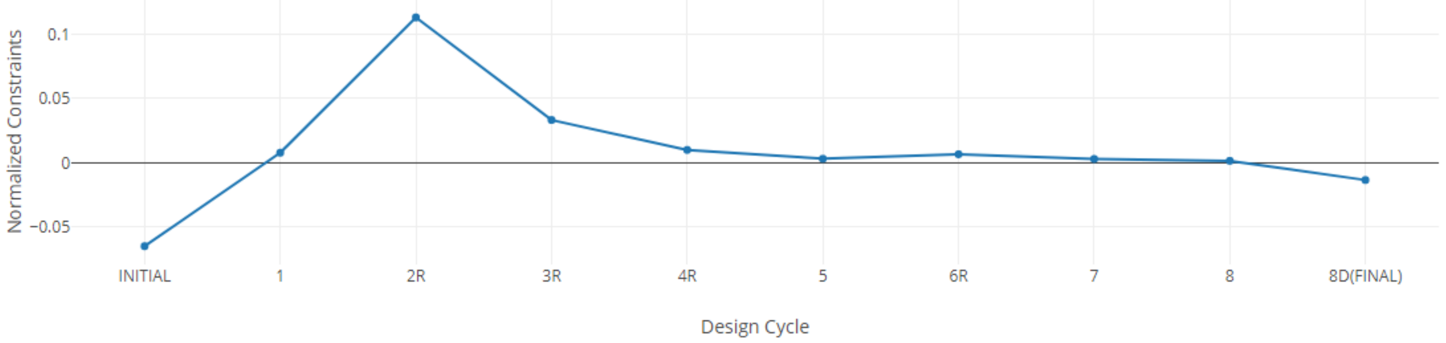
Objective



2

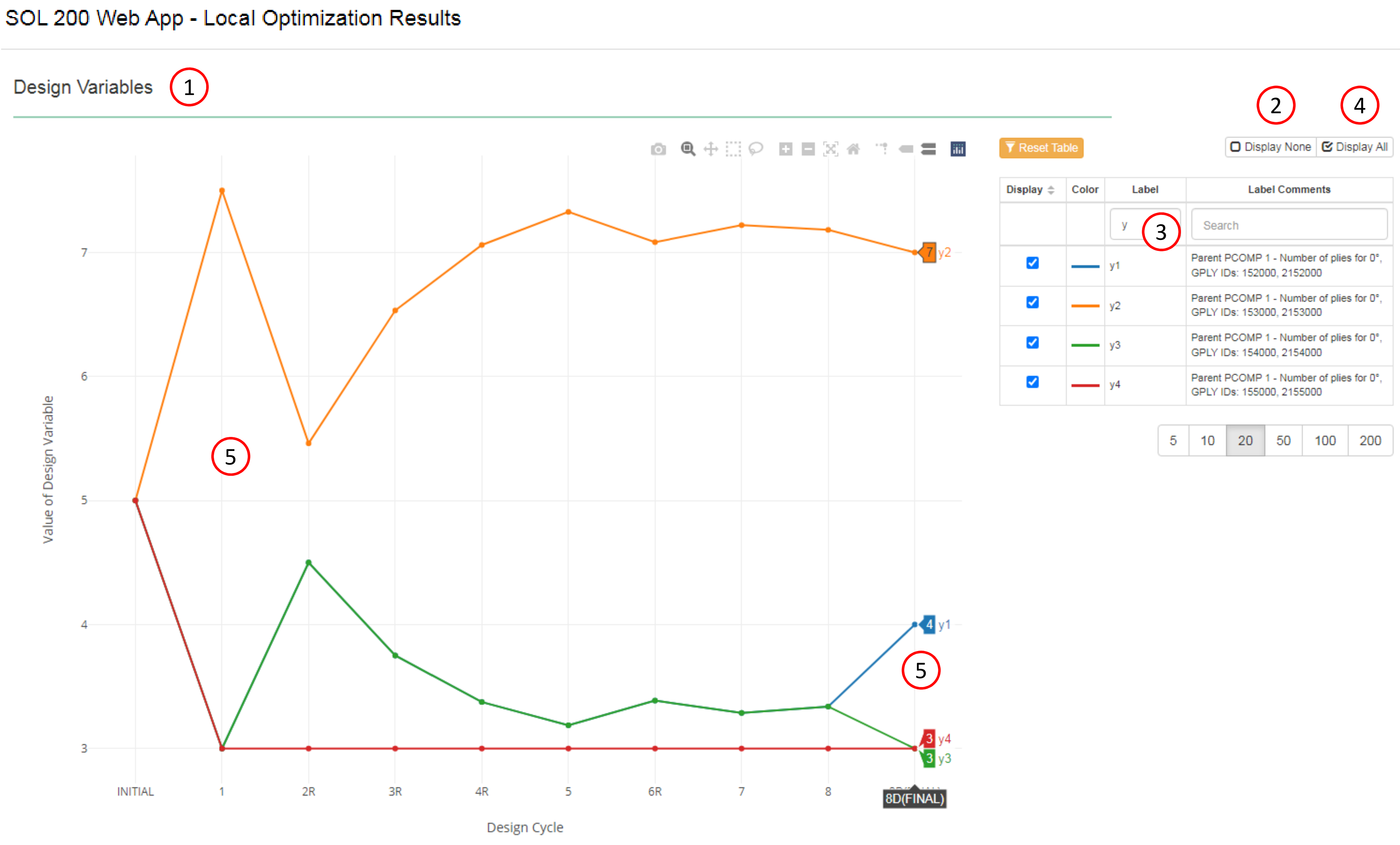
Normalized Constraints

+ Info



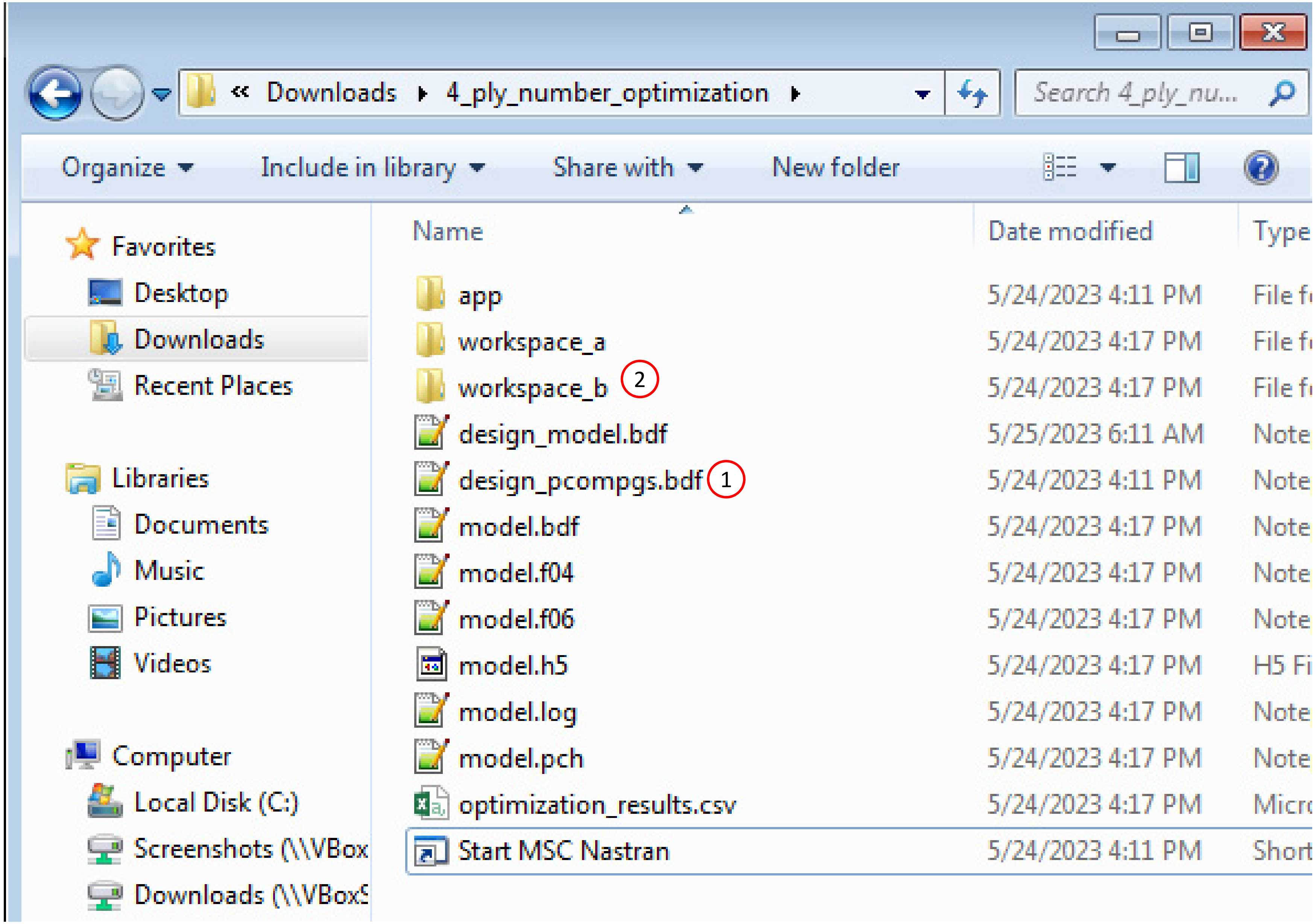
Review Optimization Results

1. Navigate to section Design Variables
2. Click Display None
3. In the search box, type y
4. Click Display All
5. Only the ply number variables, e.g. y1, y2, ..., are displayed
6. Move the mouser cursor to hover over the last design cycle and labels displaying the final variable values are visible



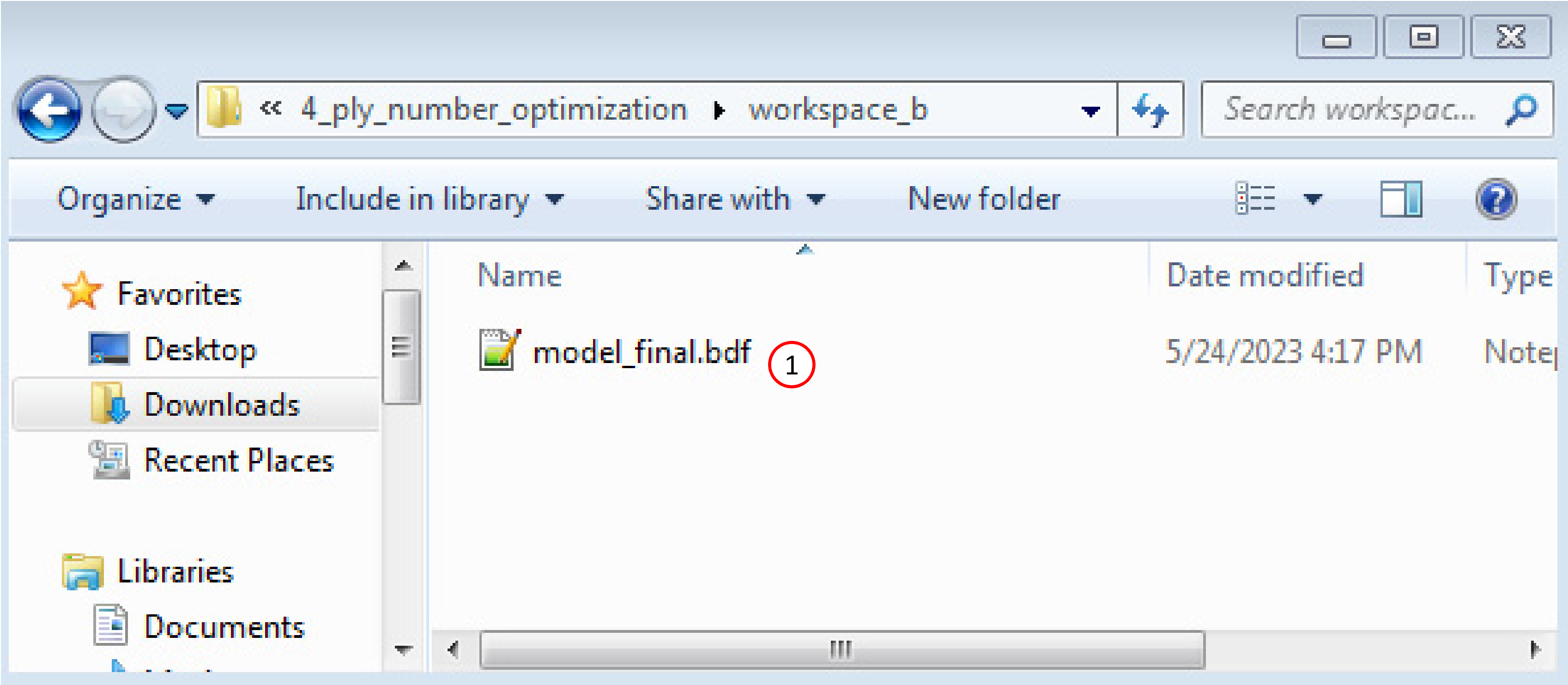
Review Optimization Results

1. Open file design_pcompgs.bdf in a text editor. A comparison will be made.
2. A new directory workspace_b has been created. Open this directory.



Review Optimization Results

1. Inside of workspace_b, open file model_final.bdf in a text editor.



Review Optimization Results

Recall the following variable results.

- Variable y1, which corresponds to GPLY ID 152000 and 2152000, has a final value of 4. This is the core layer

The following changes have been made in the BDF files found in workspace_c

1. Refer to PCOMPG 2 in both files
2. GPLY ID 152000 now has a thickness of 4.0.
   - Since the composite is symmetric, the same layers are mirrored as 2152000.
   - Since the core is represented by both 152000 and 2152000, the total thickness of the core is now 8.0.
3. The same is done for the other core layers

.\4_ply_number_optimization\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.      YES
        152000  501     1.00000 0.      YES
        2152000 501     1.00000 0.      YES
        2141000 101     .125    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.      YES
        155000  501     1.00000 0.      YES
        2155000 501     1.00000 0.      YES
        2141000 101     .125    0.      YES
        2131000 101     .125    -45.    YES
        2121000 101     .125    45.     YES
        2111000 101     .125    90.     YES
PCOMPG  4       0.0             90.     HILL
        111000  101     .125    90.     YES
        121000  101     .125    45.     YES
        131000  101     .125    -45.    YES
        141000  101     .125    0.      YES
        153000  501     1.00000 0.      YES
        2153000 501     1.00000 0.      YES
        2141000 101     .125    0.      YES
        2131000 101     .125    -45.    YES
        2121000 101     .125    45.     YES
```

.\4_ply_number_optimization\workspace_b\model_final.bdf

model_final.bdf

```
$   1   ||   2   ||   3   ||   4   ||   5   ||   6   ||
PCOMPG         2     0.0     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
          152000     501    4.       0.0             YES
         2152000     501    4.       0.0             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     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
          155000     501    3.       0.0             YES
         2155000     501    3.       0.0             YES
         2141000     101    .125     0.0             YES
         2131000     101    .125    -45.             YES
         2121000     101    .125     45.             YES
         2111000     101    .125     90.             YES
PCOMPG         4     0.0     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
          153000     501    7.       0.0             YES
         2153000     501    7.       0.0             YES
         2141000     101    .125     0.0             YES
         2131000     101    .125    -45.             YES
         2121000     101    .125     45.             YES
```

Update the Original Model

1. It should be noted that since this was a multidisciplinary optimization, the update to the file model_fina.bdf is incomplete. Manually copy the section above the BEGIN BULK delimiter from the original file (model_curved_panel_with_core.bdf) to the new file (model_final.bdf).

model_curved_panel_with_core.bdf

```
$ MSC.Nastran input file created on May       23, 2023 at 07:05:29 by
$ Patran 2022.2
$ Direct Text Input for Nastran System Cell Section
$
SOL 105
CEND
TITLE = MSC.NASTRAN JOB CREATED ON 22-MAY-23 AT 09:49:34
ECHO = NONE
SUBCASE 1
$ Subcase name : Default
   SUBTITLE=Default
   SPC = 2
   LOAD = 5
   DISPLACEMENT(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
SUBCASE 2
$ Subcase name : Default
   SUBTITLE=Default
   SPC = 2
   METHOD = 1
   VECTOR(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
   STATSUB = 1
BEGIN BULK
param   grdpnt  0
HDF5OUT PRCISION 32     CMPRMTHD LZ4     LEVEL   5
PARAM   PRTMAXIM YES
EIGRL    1      0.0             1       0
$ Elements and Element Properties for region : pcomp.1
$ Composite Property Reference Material: pcomp.502
$ Composite Material Description :
PCOMP    1       0.0            90.     HILL                    SYM
         101     .125    90.    YES
         101     .125    45.    YES
         101     .125    -45.   YES
         101     .125    0.     YES
         501     5.      0.     YES
$ Pset: "pcomp.1" will be imported as: "pcomp.1"
CQUAD4   641     1       725     726     798     724     0.      0.
```

model_final.bdf

```
$ Message from the SOL 200 Web App
$ This file was generated as follows:
$   - The head, or every line above the BEGIN BULK line, was sourced
$     from model.bdf
$       - The head is only added if the following conditions are met:
$         - There exists no INCLUDEs
$         - There is only one ANALYSIS type used
$   - SOL 200 was changed to its respective SOL number
$   - The bulk data section was sourced from model.pch
$ MSC.Nastran input file created on May       23, 2023 at 07:05:29 by
$ Patran 2022.2
$ Direct Text Input for Nastran System Cell Section
$
SOL 105
CEND
TITLE = MSC.NASTRAN JOB CREATED ON 22-MAY-23 AT 09:49:34
ECHO = NONE
SUBCASE 1
$ Subcase name : Default
   SUBTITLE=Default
   SPC = 2
   LOAD = 5
   DISPLACEMENT(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
SUBCASE 2
$ Subcase name : Default
   SUBTITLE=Default
   SPC = 2
   METHOD = 1
   VECTOR(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
   STATSUB = 1
BEGIN BULK
$*******************************************************************************
$*                                                                             *
$*                                Design Model                                 *
$*                                                                             *
$*******************************************************************************
$
```

- 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.

Part 3 – View New Core Thickness

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 Viewer

1. Navigate to the Composites section
2. Click Viewer

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Upload BDF Files

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

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Display PCOMPGs

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. In the search box, type: pcompg
5. Click the indicated icon
6. Click the indicated icon
7. If an update message appears, wait until the update is complete, then continue
8. Click the indicated icon to recolor the plies
9. The ply thickness is now displayed

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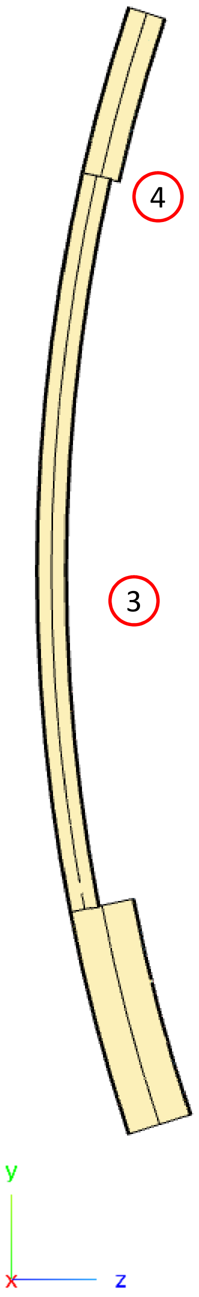
Display PCOMPGs

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



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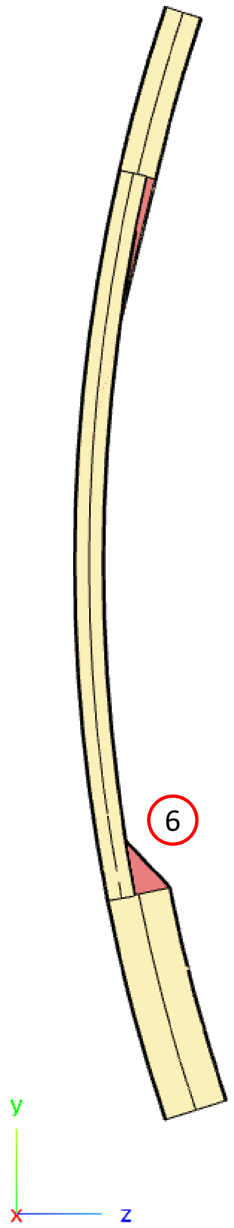
Display GPLYs

1. Click the indicated icons
2. Click Reset Table
3. In the search box, type: gply
4. Click the indicated icons
5. Click the indicated icon 2 times
6. A more realistic view of the plies is displayed

- Alternate between the literal and realistic views to gain a good understanding of how the plies are distributed across the model.



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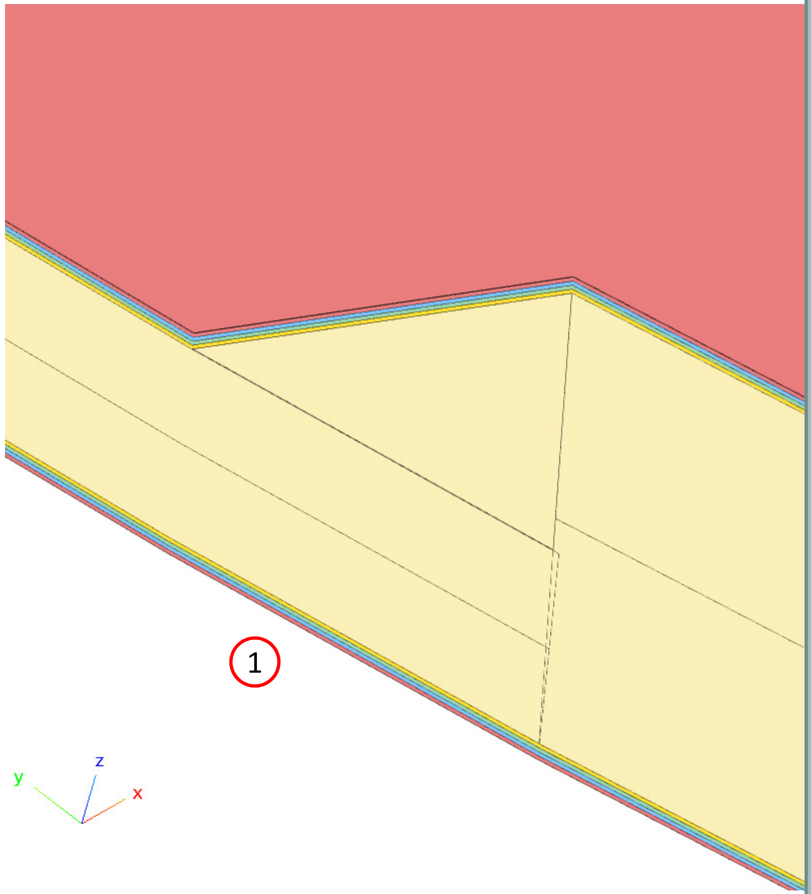
Display GPLYs

1. Rotate and zoom in to the model to see how the plies are tapered around the new core thicknesses



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Summary of Optimized Designs

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

1. ~23% mass savings. The mass of the core was reduced from 2.203330E-04 to 1.70E-04.
2. In both designs, the buckling load factor is greater than 1.0, so both designs are feasible.

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

	Starting Design	**Design After Topometry Optimization**	**Design After Core Shape and Core Number Optimization**
	Tutorial Phase B	Tutorial Phase C	Tutorial Phase D
Total Mass	3.9503E-04	2.97E-4	3.444094E-04
Mass of Non-design Region (Plies)	1.746926E-04	1.746926E-04	1.746926E-04
Mass of Design Region (Core)	**2.203330E-04**	**1.22E-04**	**1.70E-04**
Buckling Load Factor, Subcase 2	1.064771 (OK)	9.9758E-01 (NOT OK)	1.013359 (OK)

End of Tutorial

Appendix

Appendix Contents

- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)

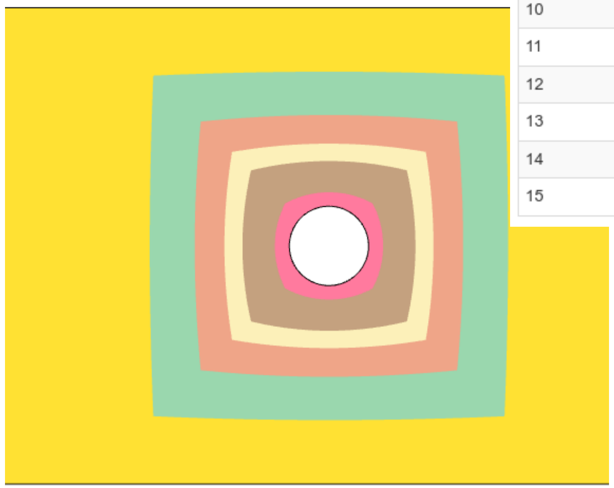
PCOMPG Zones

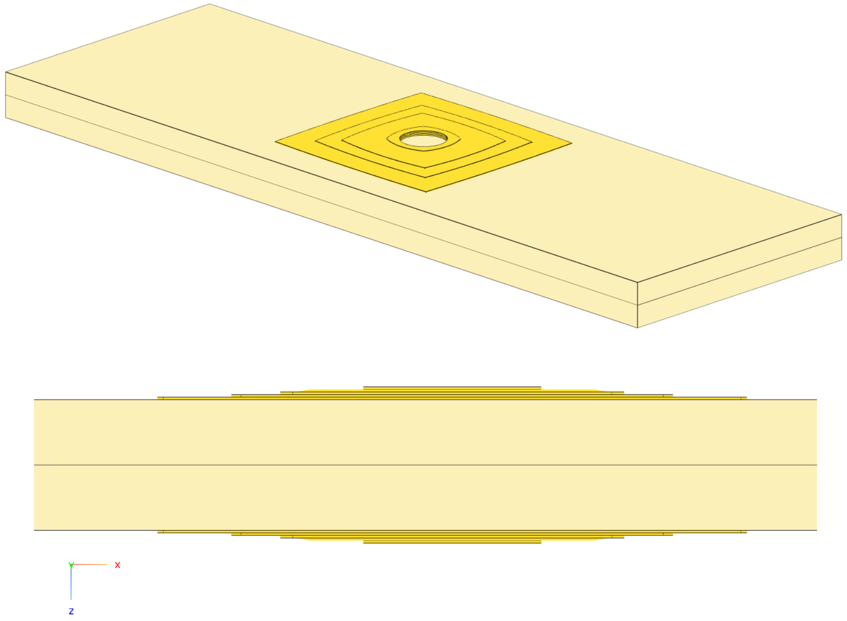
PCOMPG Zones

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

More Ply Shapes

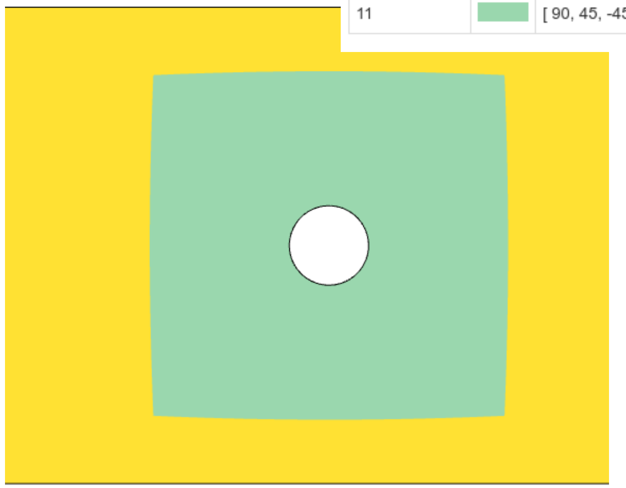
PCOMPG ID	Color	Stack
10		$[90, 45, -45, 0, 0_{Core}]_S$
11		$[90, 45, -45, 0_2, 0_{Core}]_S$
12		$[90, 45, -45, 0_3, 0_{Core}]_S$
13		$[90, 45, -45, 0_4, 0_{Core}]_S$
14		$[90, 45, -45, 0_5, 0_{Core}]_S$
15		$[90, 45, -45, 0_6, 0_{Core}]_S$

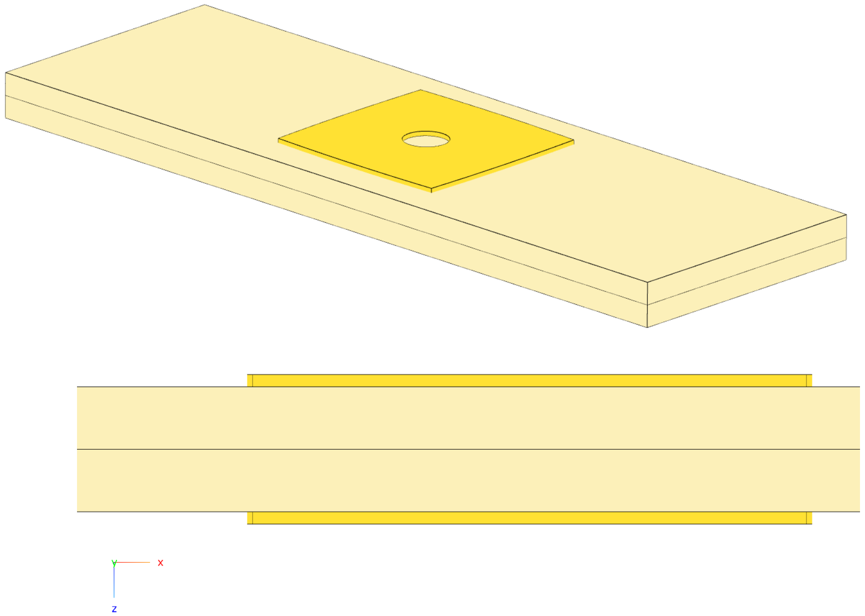




Fewer Ply Shapes

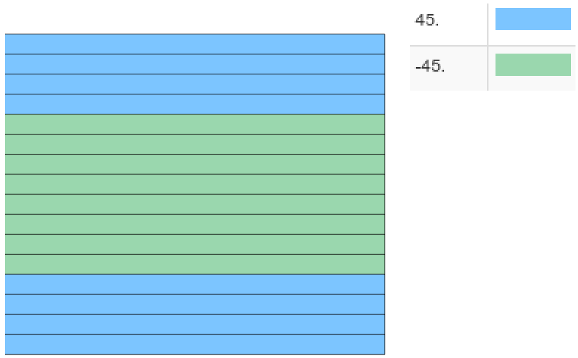
PCOMPG ID	Color	Stack
10		$[90, 45, -45, 0, 0_{Core}]_S$
11		$[90, 45, -45, 0_2, 0_{Core}]_S$



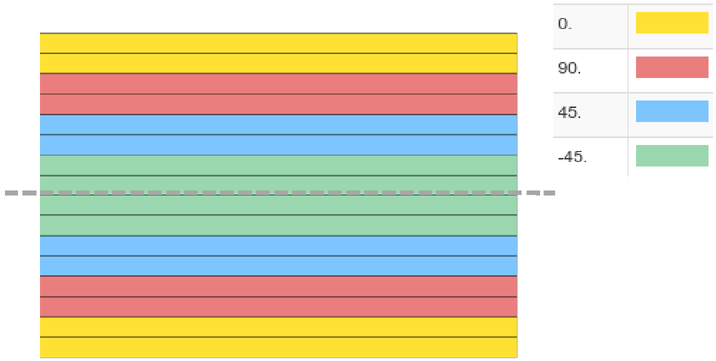


Options for Ply Number Optimization

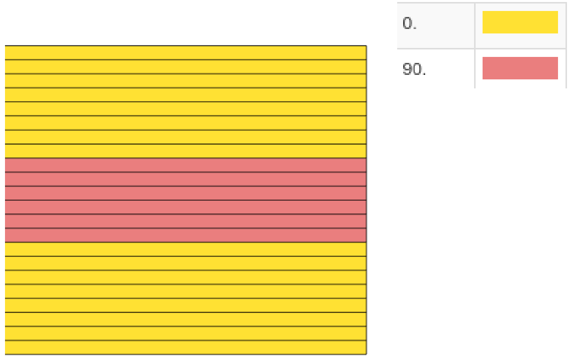
Options for Ply Number Optimization



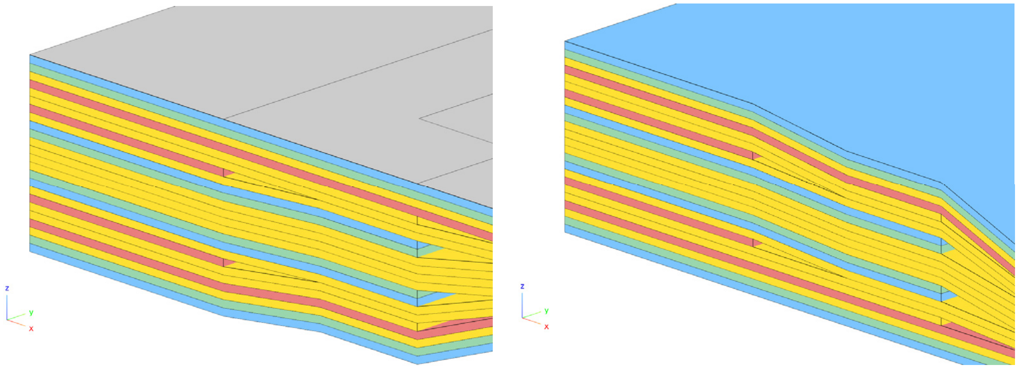
Balance



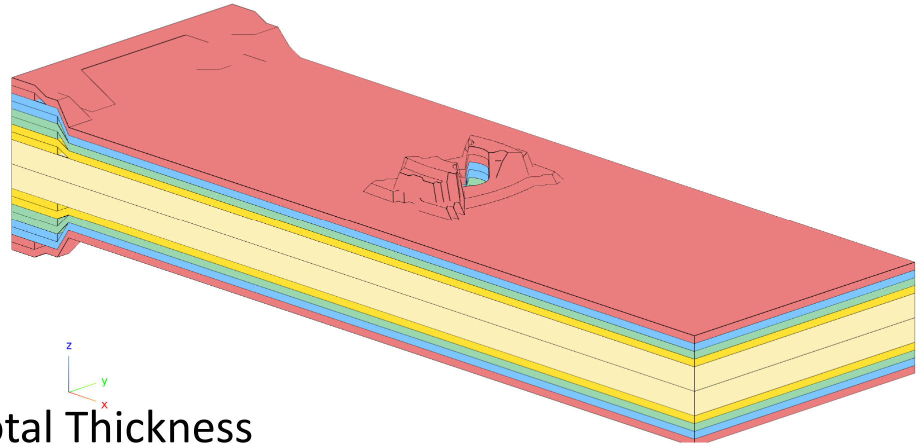
Symmetry



X% Design Rule



Z0 Offset



Total Thickness

Options for Ply Number Optimization
Constraints on Responses

Constraints on Responses

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

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Options for Ply Number Optimization
Constraints on Responses

Response	Stress	Strain
Normal-1	σ_1	ε_1
Normal-2	σ_2	ε_2
Shear-12	τ_{12}	γ_{12}
Shear-1Z	τ_{xz}	γ_{xz}
Shear-2Z	τ_{yz}	γ_{yz}
Shear Angle	θ_p	θ_p
Major Principal	σ_{max}	ε_{max}
Minor Principal	σ_{min}	ε_{min}
Maximum shear	τ_{max}	γ_{max}
Failure Index(FP) for direct stresses/strains	FP	
Failure Index(FB) for interlaminar shear-stress	FB	
Strength Ratio(SP) for direct stresses/strains	SP	
Strength Ratio(SB) for interlaminar shear-stress	SB	

Options for Ply Number Optimization

Responses in F06 File

S T R E S S E S   I N   L A Y E R E D   C O M P O S I T E   E L E M E N T S   (Q U A D 4)

	ELEMENT ID	PLY ID	STRESSES IN FIBER AND MATRIX DIRECTIONS NORMAL-1	NORMAL-2	SHEAR-12	INTER-LAMINAR STRESSES SHEAR XZ-MAT	SHEAR YZ-MAT	PRINCIPAL STRESSES (ZERO SHEAR) ANGLE	MAJOR	MINOR	MAX SHEAR
0	8264	1	1.78751E+01	-1.68306E+01	2.41331E+00	4.82031E-02	-1.05478E-01	3.96	1.80421E+01	-1.69976E+01	1.75198E+01
0	8264	2	-4.22498E+01	-6.36100E+00	1.10039E+01	1.43883E-01	-1.50335E-01	74.24	-3.25576E+00	-4.53551E+01	2.10497E+01
0	8264	3	-2.06818E+01	-9.60743E+00	-1.06974E+01	2.36897E-01	-1.93942E-01	-58.68	-3.09908E+00	-2.71901E+01	1.20455E+01
			σ_1	σ_2	τ_{12}	τ_{xz}	τ_{yz}	θ_p	σ_{max}	σ_{min}	τ_{max}

S T R A I N S   I N   L A Y E R E D   C O M P O S I T E   E L E M E N T S   (Q U A D 4)

	ELEMENT ID	PLY ID	STRAINS IN FIBER AND MATRIX DIRECTIONS NORMAL-1	NORMAL-2	SHEAR-12	INTER-LAMINAR STRAINS SHEAR XZ-MAT	SHEAR YZ-MAT	PRINCIPAL STRAINS (ZERO SHEAR) ANGLE	MAJOR	MINOR	MAX SHEAR
0	8264	1	-3.81162E-04	1.87582E-03	2.83217E-04	0.0	0.0	86.42	1.88467E-03	-3.90012E-04	2.27468E-03
0	8264	2	6.05720E-04	8.88938E-04	-2.25698E-03	0.0	0.0	-48.58	1.88467E-03	-3.90012E-04	2.27468E-03
0	8264	3	8.88938E-04	6.05720E-04	2.25698E-03	0.0	0.0	41.42	1.88467E-03	-3.90012E-04	2.27468E-03
			ε_1	ε_2	γ_{12}	γ_{xz}	γ_{yz}	θ_p	ε_{max}	ε_{min}	γ_{max}

F A I L U R E   I N D I C E S   F O R   L A Y E R E D   C O M P O S I T E   E L E M E N T S   (Q U A D 4)

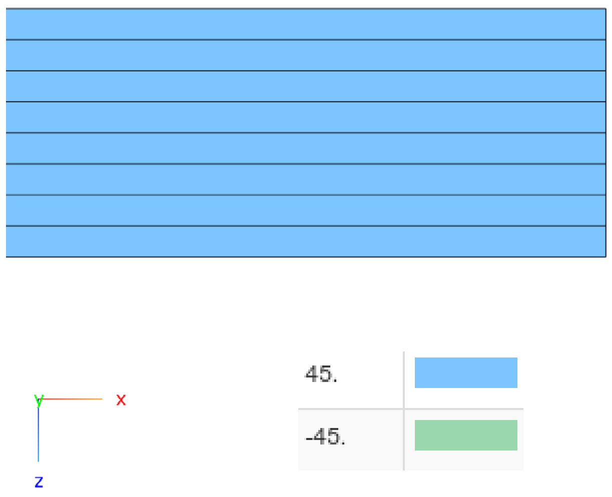
ELEMENT ID	FAILURE THEORY	PLY ID	FP=FAILURE INDEX FOR PLY (DIRECT STRESSES/STRAINS)	FB=FAILURE INDEX FOR BONDING (INTER-LAMINAR STRESSES)	FAILURE INDEX FOR ELEMENT MAX OF FP,FB FOR ALL PLIES	FLAG
8264	HILL	1	0.0226			
				0.0012		
[…]						
		17	0.0668			
				0.0012		
		18	0.2976			
					0.2976	
			FP	FB		

Balance

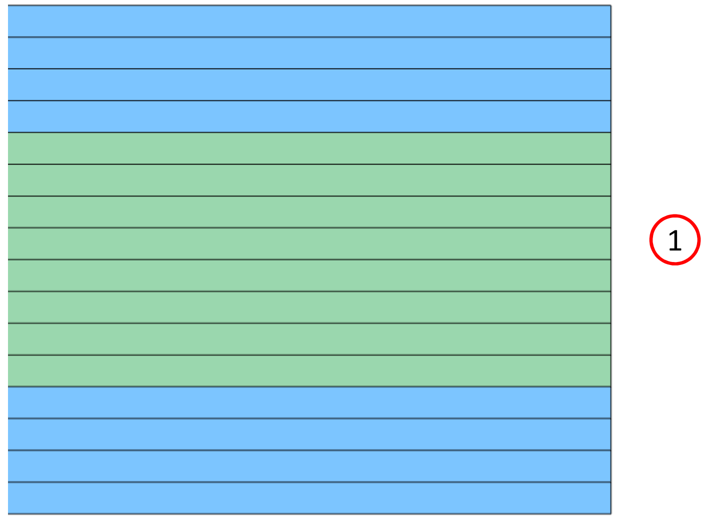
1. Ensure the starting composite has both +θ AND -θ plies, e.g. ±45°, ±60°, etc.

2. Use Link Plies in the web app

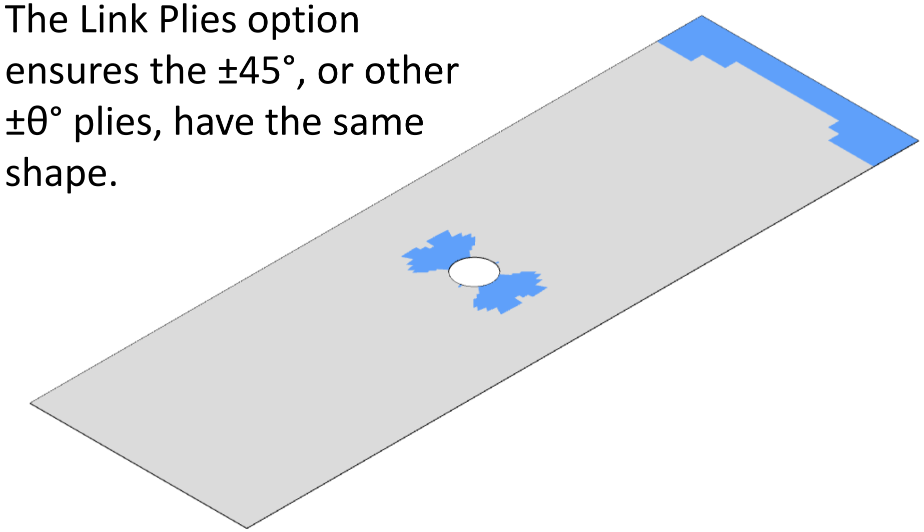
Not Balanced
[45°]



Balanced
[45°/-45°]

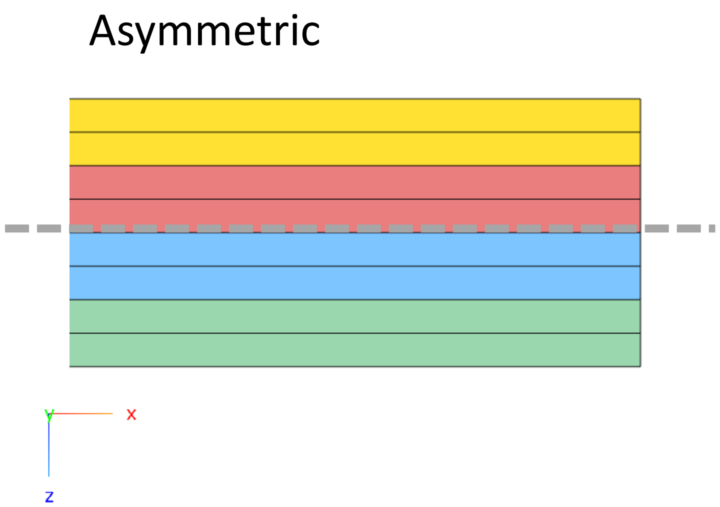


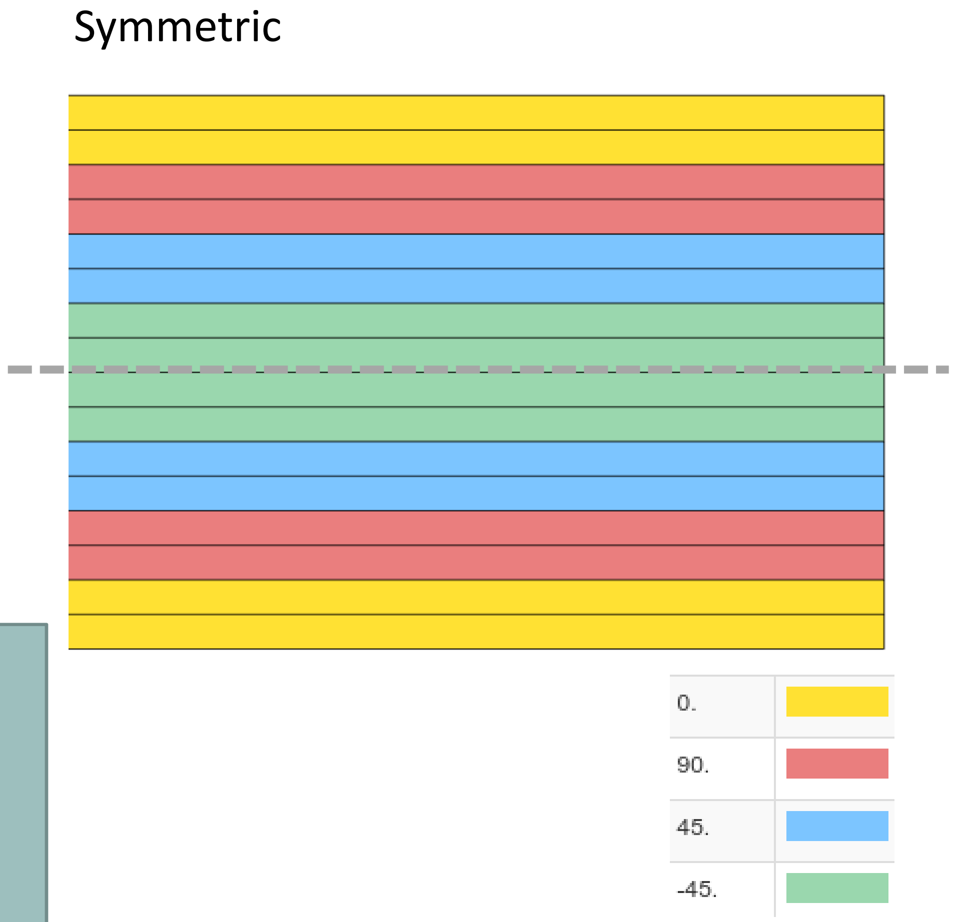
The Link Plies option ensures the ±45°, or other ±θ° plies, have the same shape.



Symmetry

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





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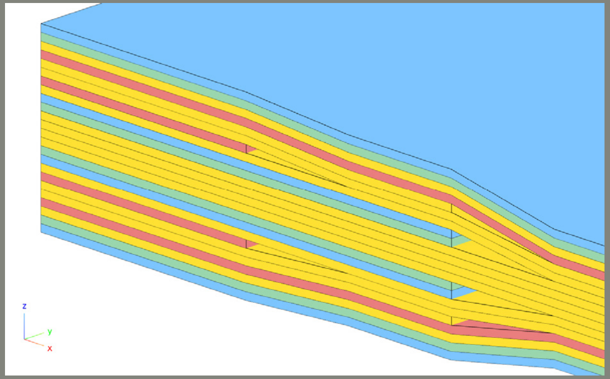
Offset to Outer Mold Line

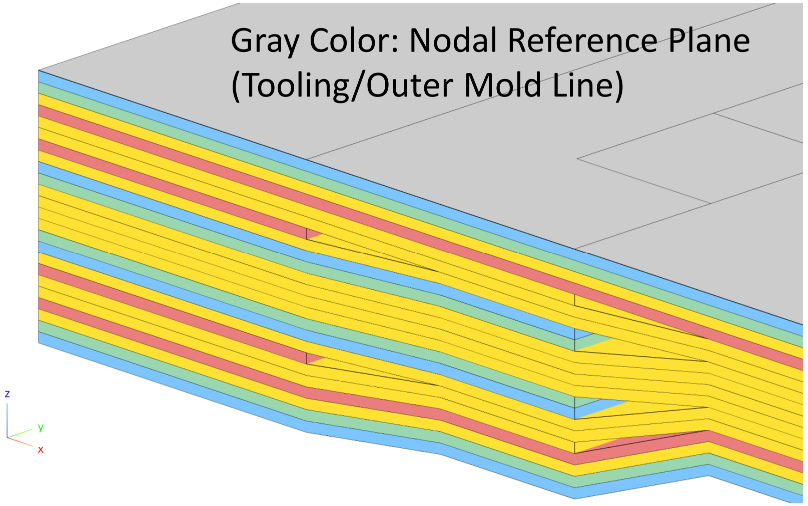
Different manufacturing methods require different offsets.

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

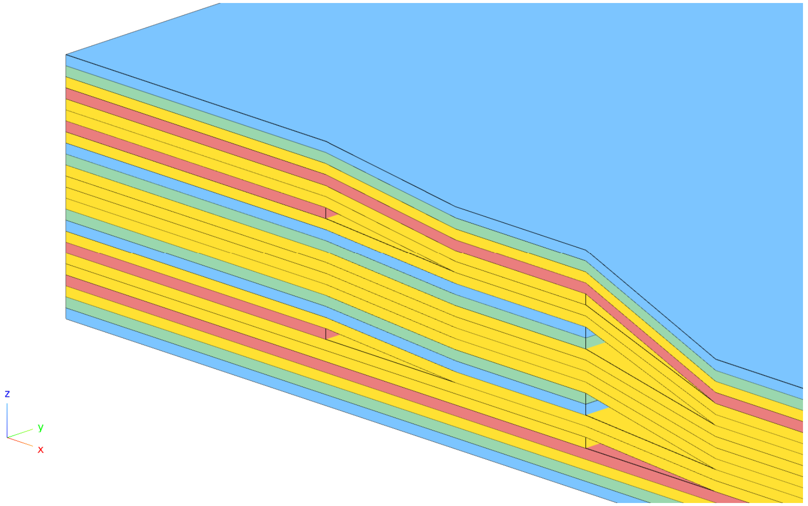
Offset Default (No Offset)



Offset Bottom



Offset Top



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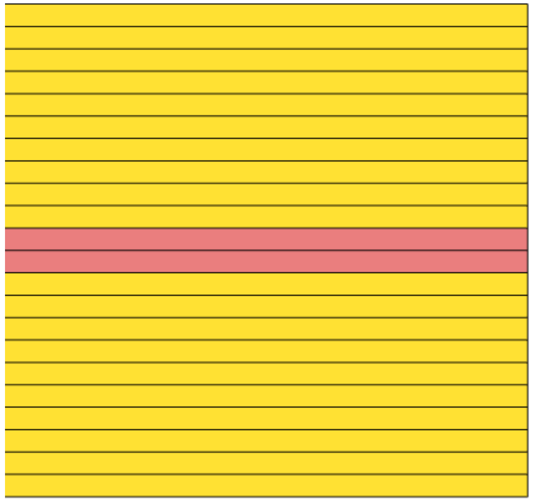
10% Design Rule

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

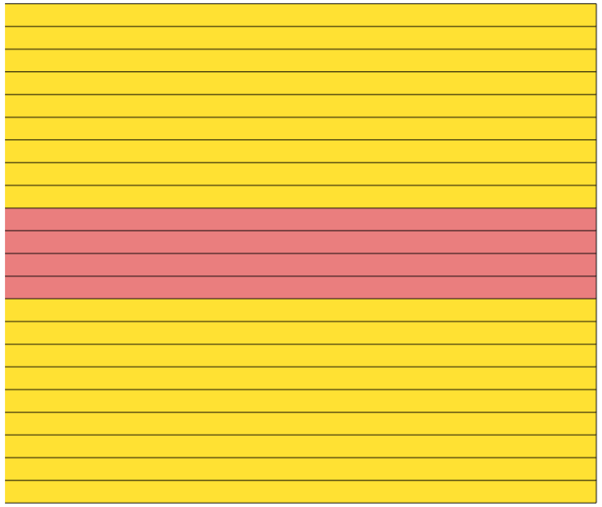
1. Use % Rule Design to put a lower bound on the percentage of specific ply angles

No percent constraint



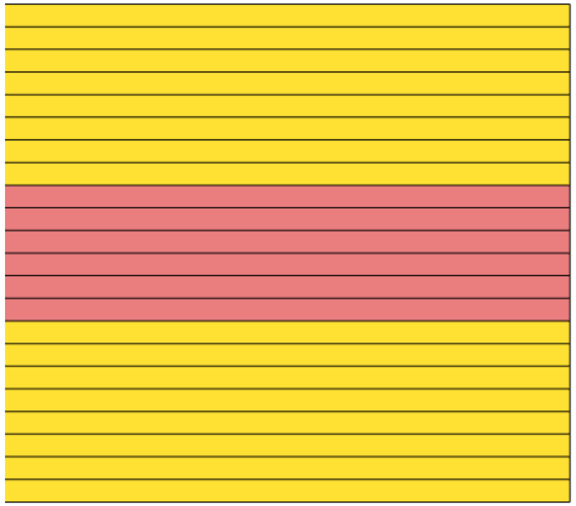
2 plies / 22 plies x 100 = 9%

Minimum of 10% of plies are 90°



4 plies / 22 plies x 100 = 18%

Minimum 20% of plies are 90°



6 plies / 22 plies x 100 = 27%

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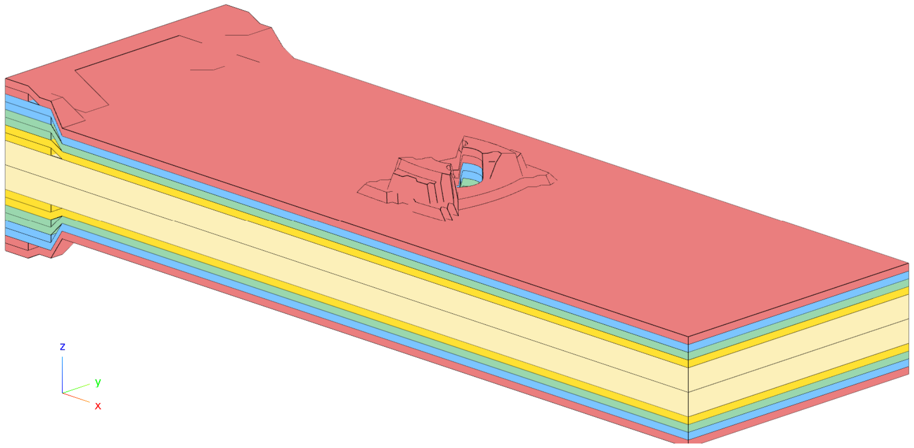
Total Thickness

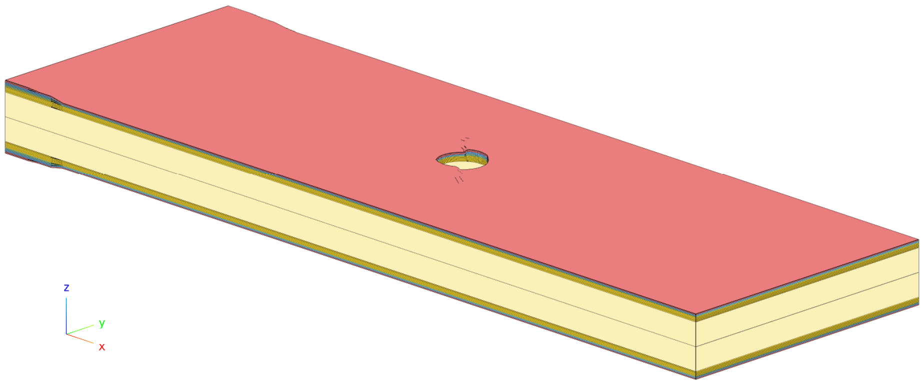
The optimizer may inadvertently produce a composite that is very thick.

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

No Total Thickness Constraint



With Total Thickness Constraint



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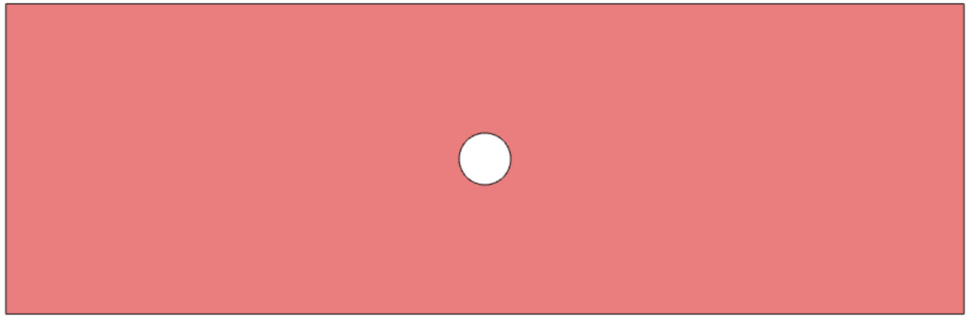
GPLY ID Numbering Convention (sPLC000)

GPLY ID Numbering Convention (sPLC000)

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

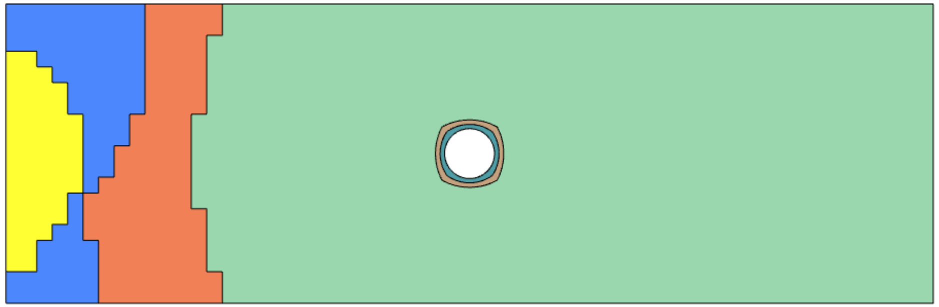
Parent PCOMP

PCOMP	1	



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

Child PCOMPGs



PCOMPG	2	
PCOMPG	3	
PCOMPG	4	
PCOMPG	5	
PCOMPG	6	
PCOMPG	7	

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

GPLY ID Numbering Convention (sPLC000)

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

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

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

Parent PCOMP

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

Child PCOMPG

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

Ply Numbering Convention (sPLC000)

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