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

AN MSC NASTRAN SOL 200 TUTORIAL

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Composite Workshop

This workshop is phase A 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

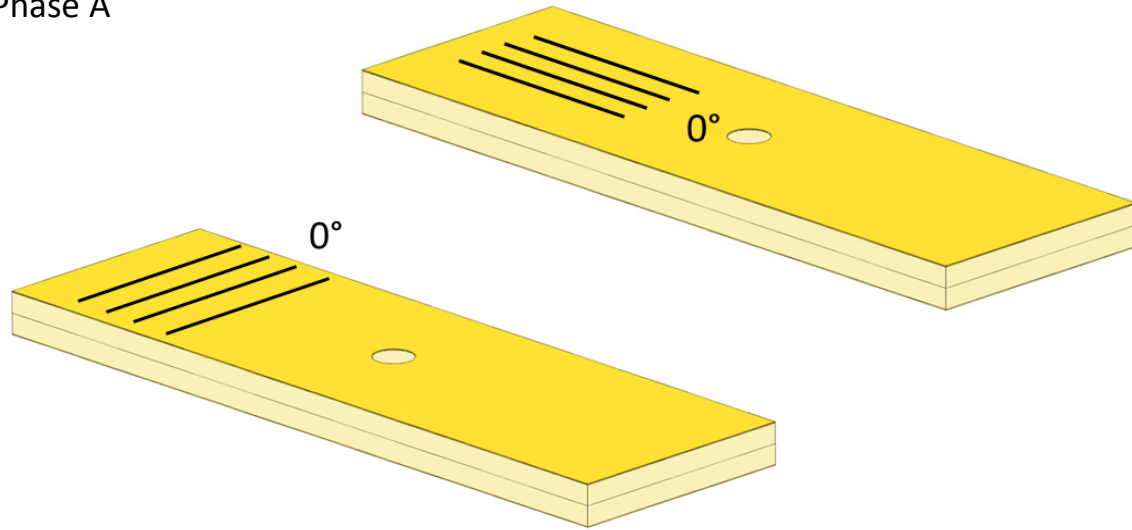- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

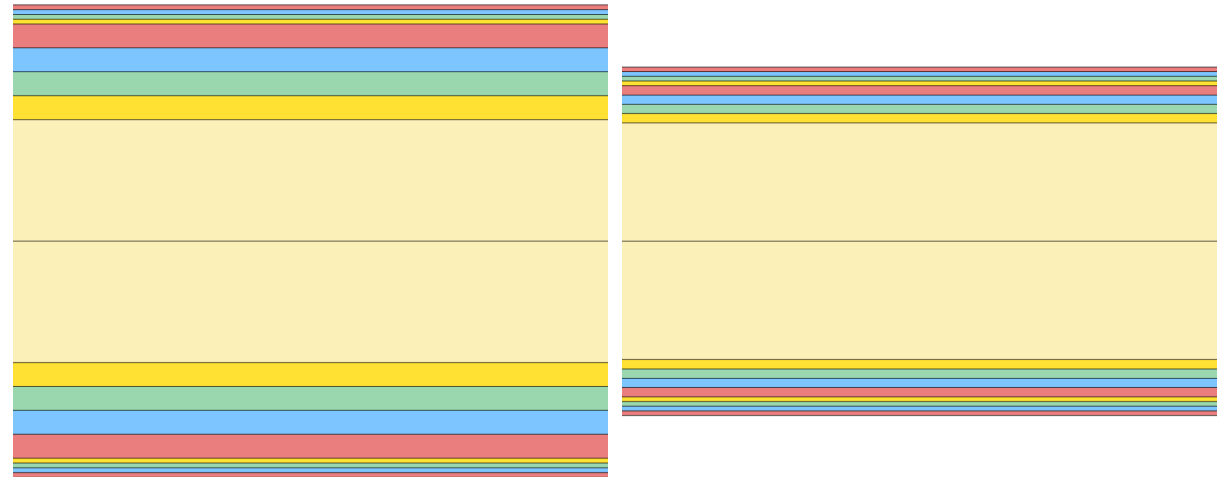| 0° Direction Optimization	Baseline Ply Number Optimization

Composite Workshop

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

Phase A

Phase B

0°

0°

0° Direction Optimization

Baseline Ply Number Optimization

Composite Workshop

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

Phase C

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

- Manually create PLY000i Files

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

Phase D

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

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

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

Phase E

Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization

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

- Tools Used: SOL 200 Web App (Stacking Sequence and Viewer web apps) and MSC Nastran
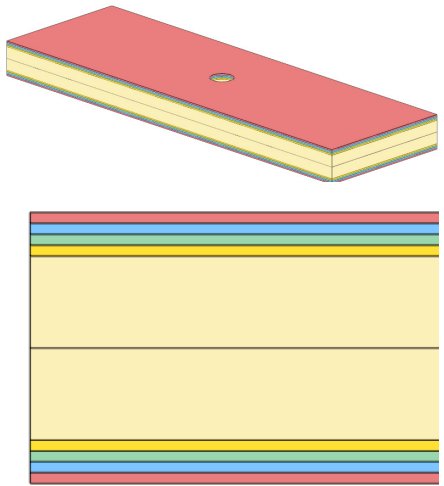
Ply Shape Optimization > Ply Number Optimization > Stacking Sequence Optimization
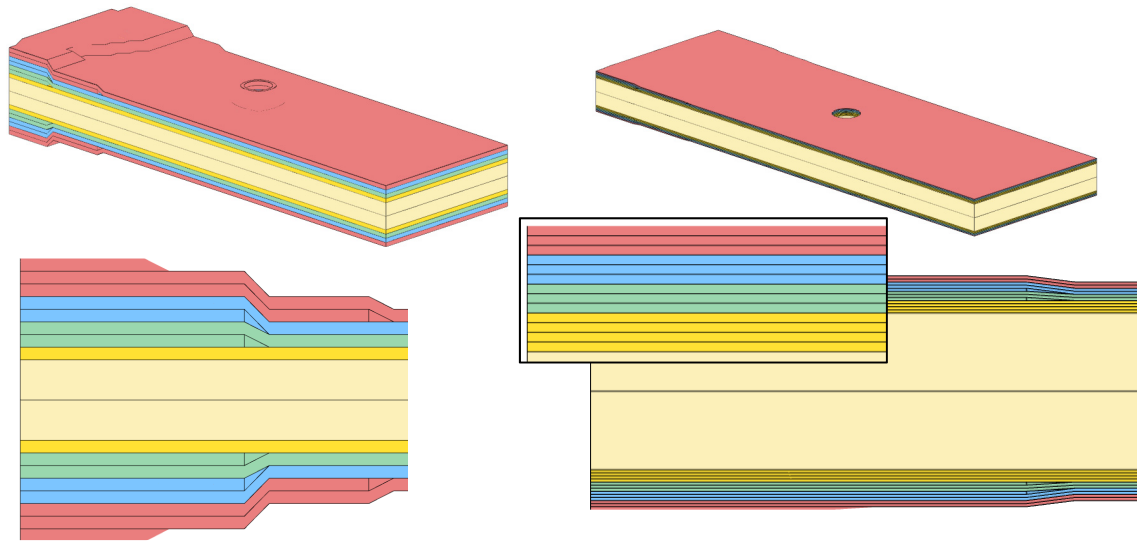
Composite Workshop
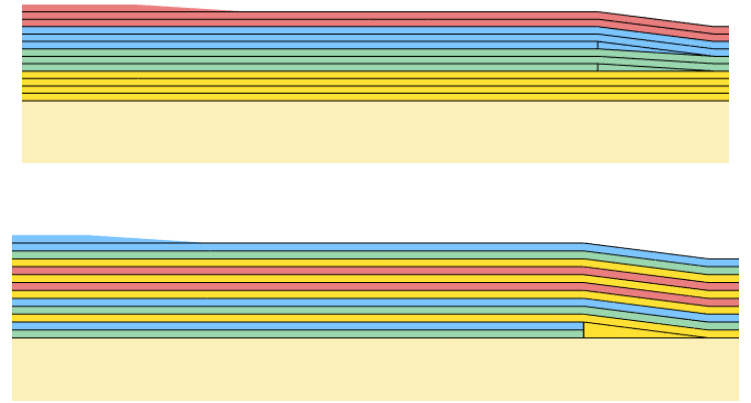
This workshop is phase A of a 5-phase workshop.

Phase C

Phase D

Phase E

Ply Shape Optimization

Ply Number Optimization

Stacking Sequence Optimization

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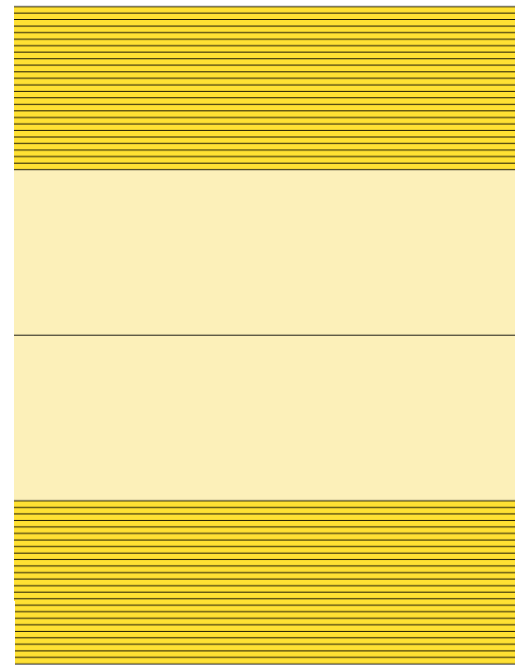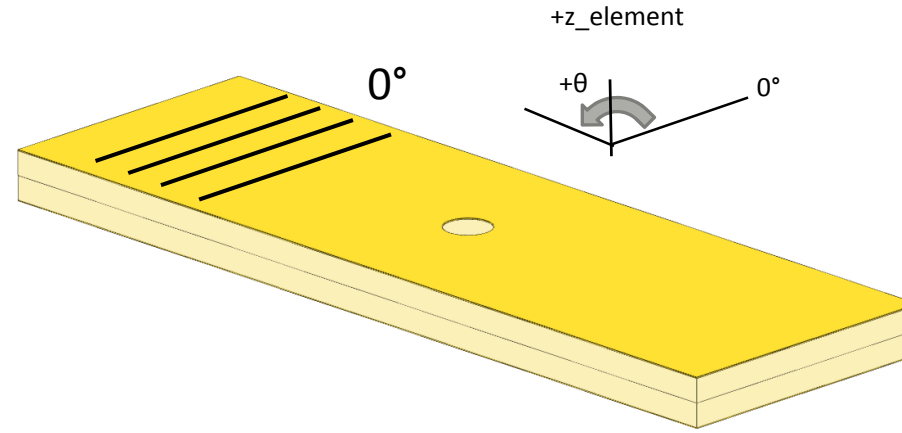# Goal: Determine the optimal 0° direction of the composite

The x-axis of the material coordinate system typically defines the direction of the 0° plies.

Consider the composite shown, which consists of a core and 0° plies. This composite is to satisfy failure index constraints.
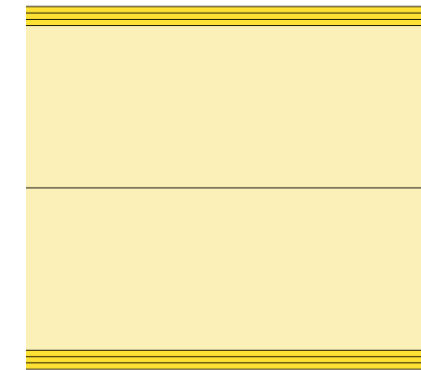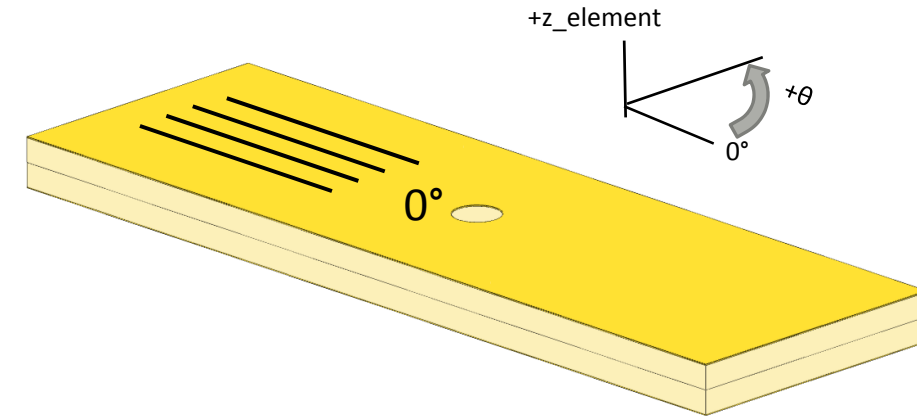
If the 0° direction (x-axis of the material coordinate system) is not optimal, the number of plies determined will be suboptimal. In this example, a total of 48 plies are required if the direction of the 0° plies is suboptimal, but 3 plies are required if the 0° direction is optimal.

This tutorial details how to use the MSC Nastran SOL 200's optimizer to optimize the 0° direction of the composite.

Suboptimal 0° Direction

$[0_{24}/ 0_{core}]_s$

Optimal 0° Direction

$[0_3/ 0_{core}]_s$

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

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Details of the structural model

+z_element

+θ   0°

118mm x 38.1mm
Radius: 3.175mm

Edge is
Clamped

0°

Subcase 2 – Transverse Load

Subcase 1 - Tension

$[0/ 0_{core}]_s$
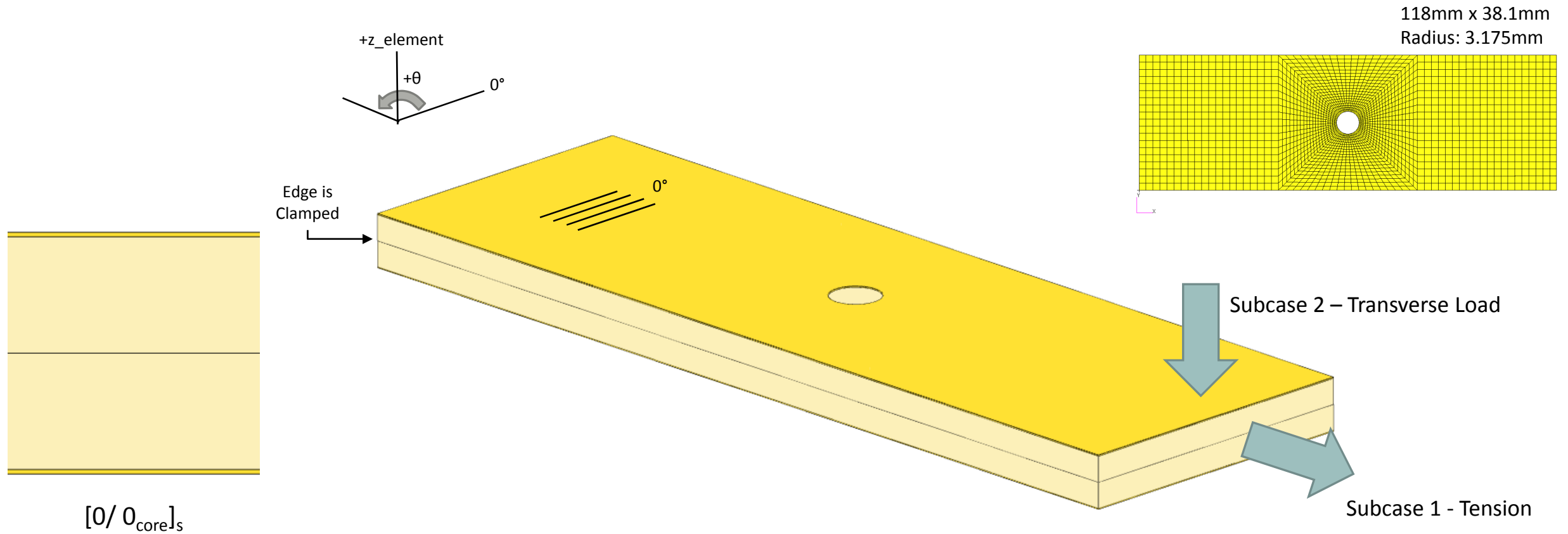
Details of the Composite Layers

This composite consists of 4 layers.

The PCOMP entry defines only 2 layers, but the LAM=SYM option indicates that the composite is symmetric. Internally, layers 3 and 4 are generated and stored.

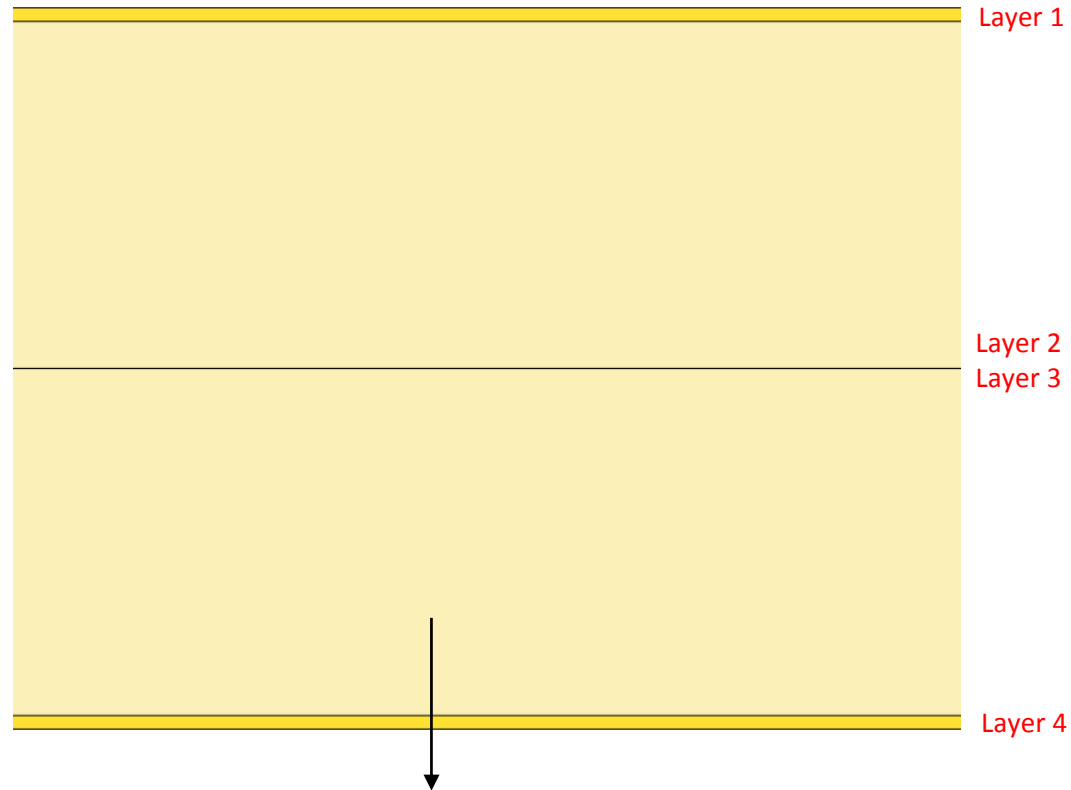- Layers 2 and 3 correspond to the core.

- Layers 1 and 4 correspond to the 0° ply.

Layer 1

Layer 2
Layer 3

Layer 4

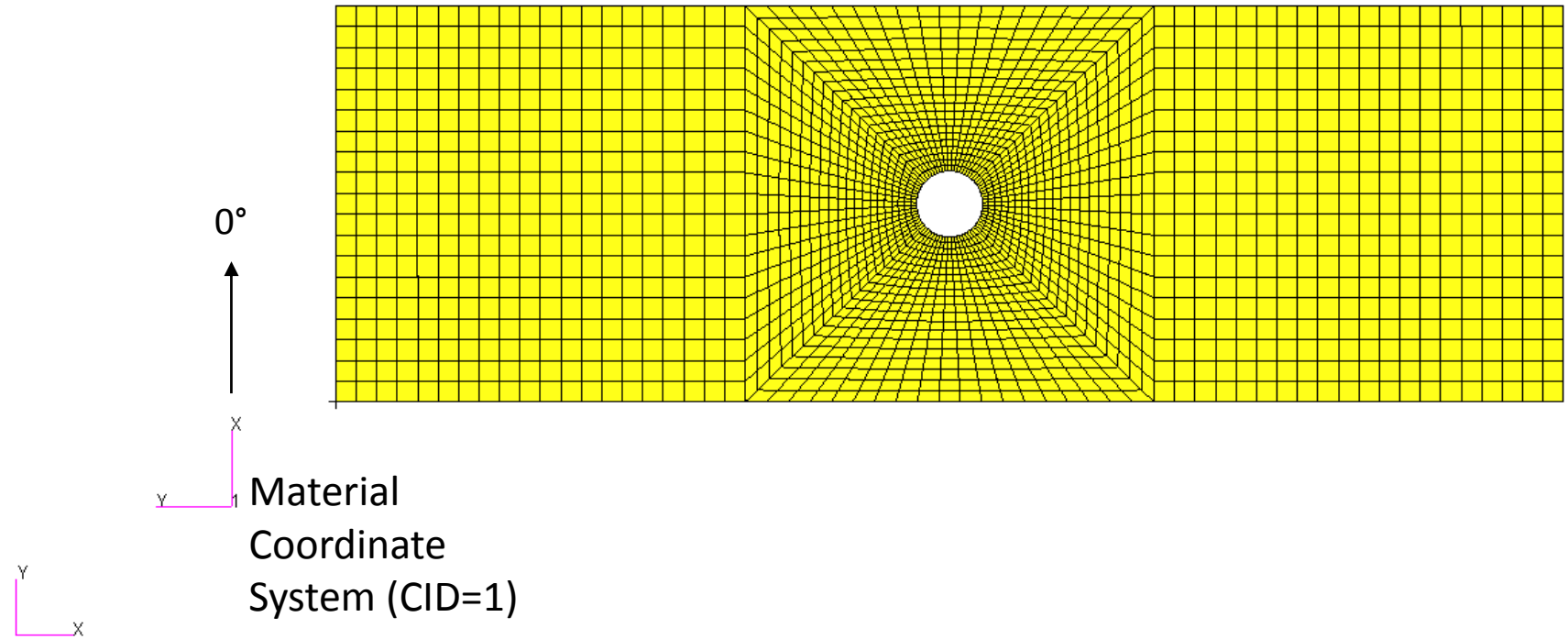0°

0° (Core)

+z_element

```
PCOMP     1                           90.     HILL                          SYM
          101       .125      0.        YES  Layer 1
          501       3.175     0.        YES  Layer 2
```

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

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Material Coordinate System

1. The 0° direction corresponds to the x-axis of the material coordinate system.

0°

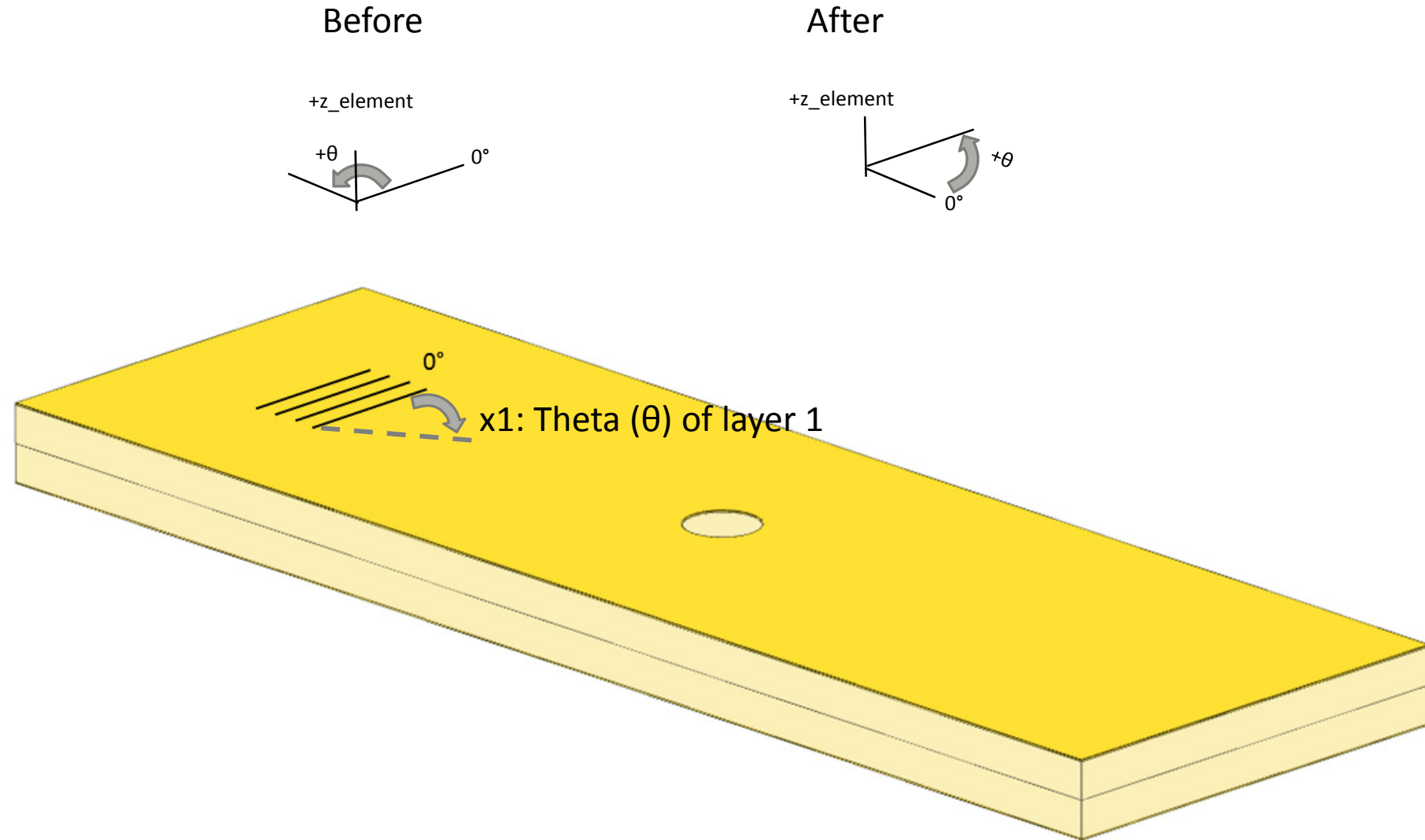Material Coordinate System (CID=1)

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Material Coordinate System

- The material coordinate system is defined by a CORD2R (CID=1) entry and the CQUAD4 entry's 8th field points to CID=1.

```
CQUAD4     1429      1        2393     2374     2452     2411     1        0.
CQUAD4     1430      1        2411     2452     2453     2410     1        0.
CQUAD4     1431      1        2410     2453     2454     2409     1        0.
CQUAD4     1432      1        2409     2454     2455     2408     1        0.
CQUAD4     1433      1        2408     2455     2456     2407     1        0.
CQUAD4     1434      1        2407     2456     2457     2406     1        0.
CQUAD4     1435      1        2406     2457     2458     2405     1        0.
CQUAD4     1436      1        2405     2458     2459     2404     1        0.
CQUAD4     1437      1        2404     2459     2460     2403     1        0.
CQUAD4     1438      1        2403     2460     2461     2402     1        0.
CQUAD4     1439      1        2402     2461     2462     2401     1        0.
CQUAD4     1440      1        2401     2462     2463     2400     1        0.
CQUAD4     1441      1        2400     2463     2464     2399     1        0.
CQUAD4     1442      1        2399     2464     2465     2398     1        0.
CQUAD4     1443      1        2398     2465     2466     2397     1        0.
CQUAD4     1444      1        2397     2466     2467     2396     1        0.
CQUAD4     1445      1        2396     2467     2468     2395     1        0.
CQUAD4     1446      1        2395     2468     2469     2394     1        0.
CQUAD4     1447      1        2394     2469     2431     2412     1        0.
CQUAD4     1448      1        2374     2375     2470     2452     1        0.
CQUAD4     1449      1        2452     2470     2471     2453     1        0.
CQUAD4     1450      1        2453     2471     2472     2454     1        0.
CQUAD4     1451      1        2454     2472     2473     2455     1        0.
CQUAD4     1452      1        2455     2473     2474     2456     1        0.
CORD2R     1                 -10.     -10.     0.       -10.     -10.     14.14214
           -10.    4.142136 0.
```

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Optimization of the 0° direction

1. This optimization seeks to find the optimal direction of the 0° direction. Variable x1 corresponds to the angle of layer 1 on the PCOMP entry. The final value/angle of x1 represents the offset in which the material coordinate system must be rotated to yield an optimal 0° direction.

Before

After

+z_element

+θ

0°

+z_element

+θ

0°

0°

x1: Theta (θ) of layer 1

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Optimization Problem Statement

Design Variables

x1: THETA1, Theta of layer 1 (0°), of PCOMP 1 (pcomp.1)

Gradient based optimizers experience difficulties with variable values of 0. Typically, theta is defined between -90° and 90°, but with the initial value equal to 0°, issues are expected during the optimization. Instead, the range between -90 and 90 is offset by +360. The new range of values is between 270° and 450° and the initial value is set to 360°.

270 < x1 < 450

Initial x1 = 360

PCOMP | 1
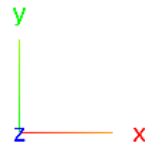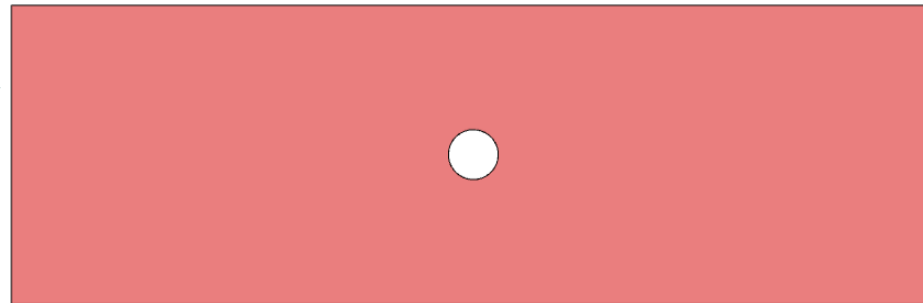
Design Objective

Minimize R0

R0 = max(a1, a2)

a1: Compliance of subcase 1
a2: Compliance of subcase 2

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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

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Tutorial

Tutorial Overview

1. Start with a .bdf or .dat file

2. Use the SOL 200 Web App to:
   - Convert the .bdf file to SOL 200
     - Design Variables
     - Design Objective

Special Topics Covered

Determination of the optimal 0° direction - The most lightweight composites feature 0° plies in the direction of the load. This tutorial demonstrates how to determine the optimal 0° direction.

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SOL 200 Web App Capabilities

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

Compatibility

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

Benefits

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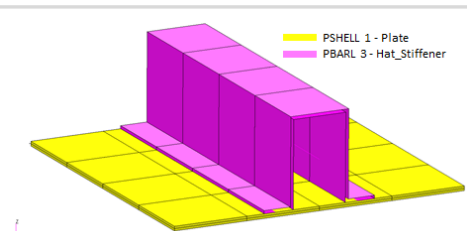
Web Apps

Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.
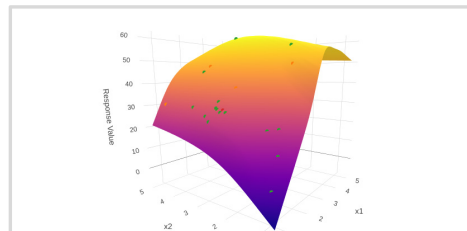
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)
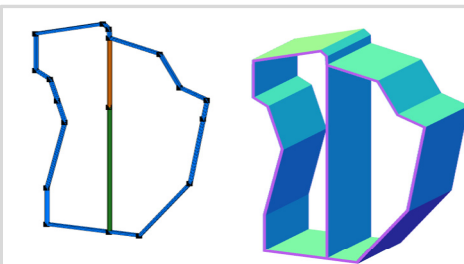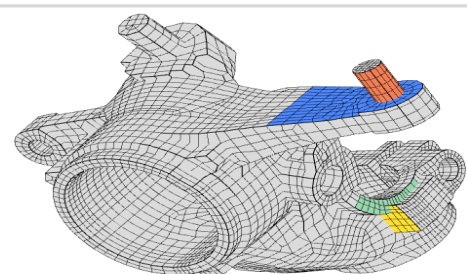
PBMSECT Web App
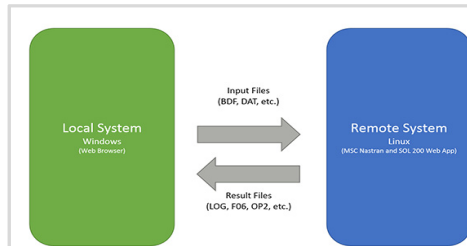Generate PBMSECT and PBRSECT entries graphically
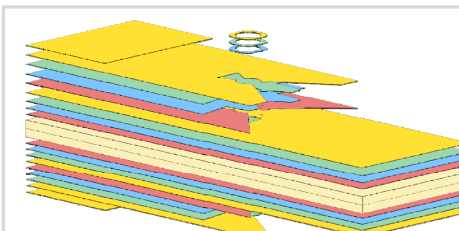
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries
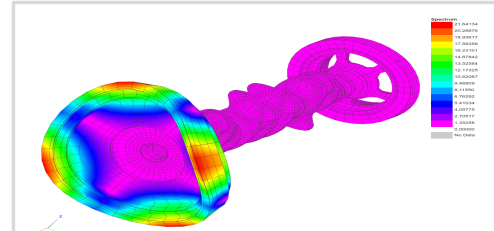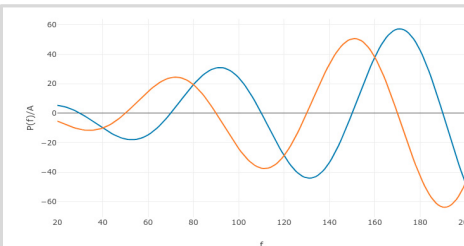
Post-processor Web App
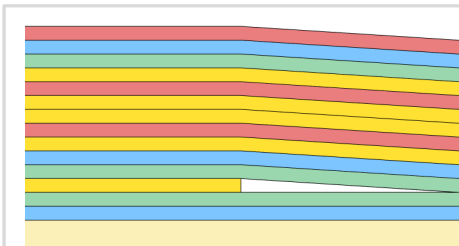View MSC Nastran results in a web browser on Windows and Linux

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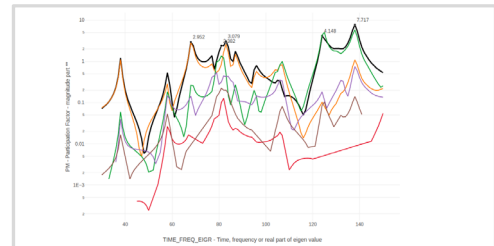Use a web application to configure and perform shape optimization.

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

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

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

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

Before Starting

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

- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran_working_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.
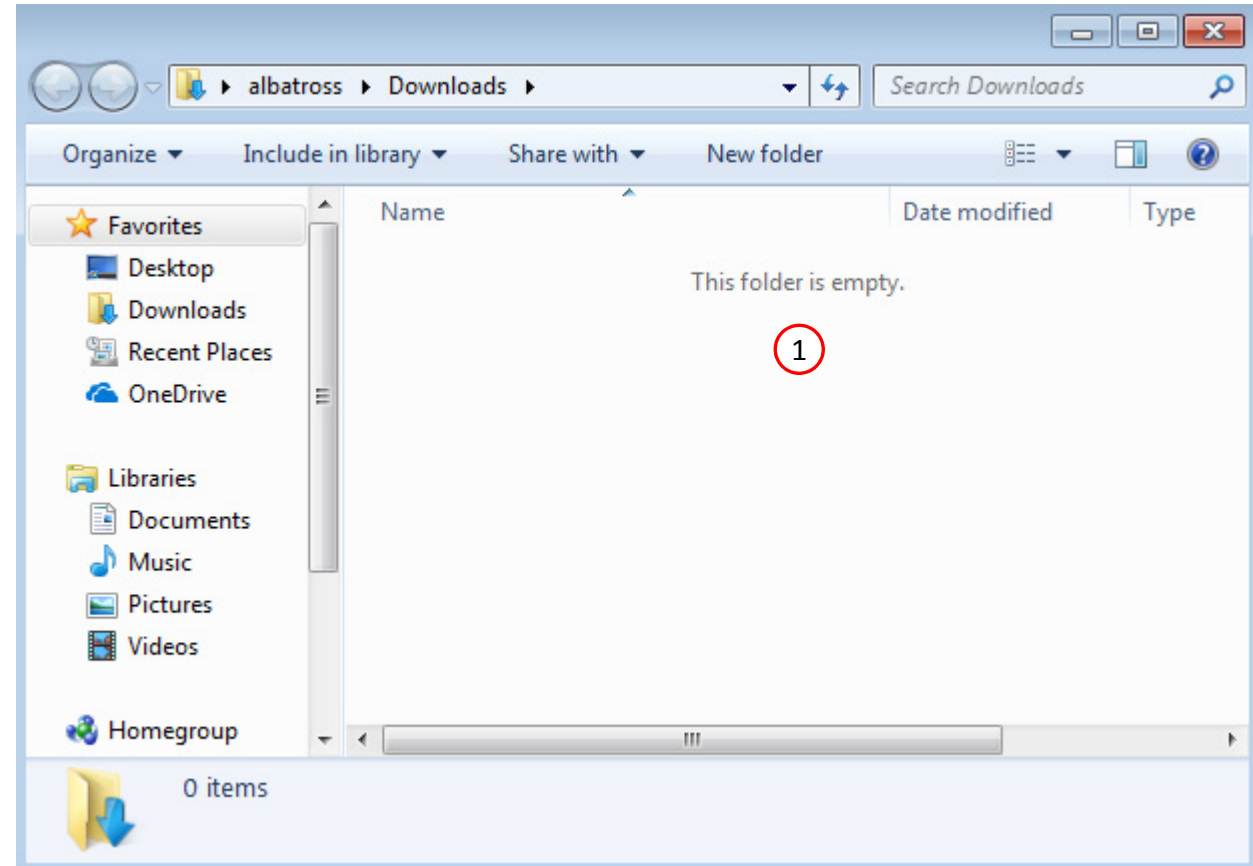
Go to the User's Guide

1. Click on the indicated link

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

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SOL 200 Web App

Select a web app to begin

Optimization for SOL 200

Multi Model Optimization

Machine Learning | Parameter Study

HDF5 Explorer

Viewer

1 Tutorials and User's Guide

Full list of web apps

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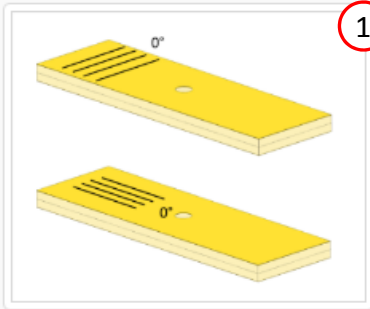Technology Partner

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.

Composites Tutorials

	Title and Description
	Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite ① The goal of this 5-phase tutorial series is to optimize a composite coupon, with a core, and produce a lightweight composite that satisfies failure index constraints. This first phase involves determining the optimal 0° direction of a composite. It is best practice to align the 0° plies in the direction of the load. Not doing so will more than likely produce a suboptimal composite that is heavier than necessary. This tutorial demonstrates the use of MSC Nastran's optimizer to determine the optimal 0° direction of a composite. An optimization is performed to maximize the stiffness of the composite for multiple load cases and while varying the angle of the 0° plies. Ultimately, the best 0° direction is determined. This is the first phase in a 5-phase tutorial series. Starting BDF Files: Link ② Solution BDF Files: Link

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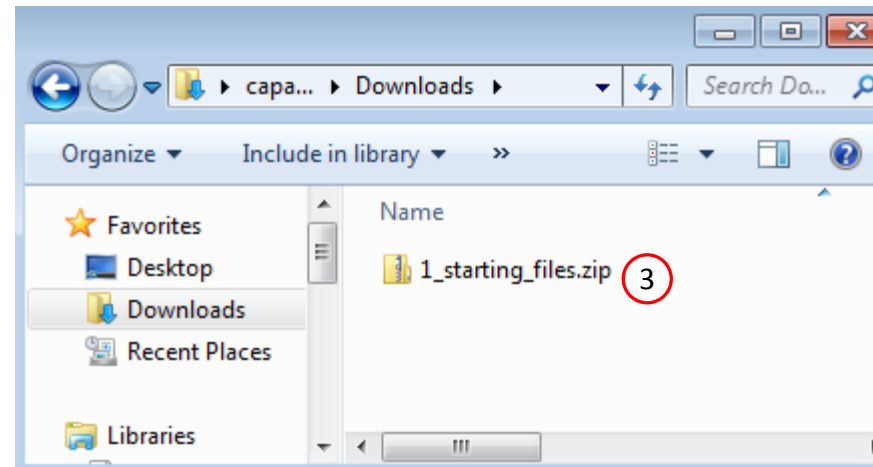
Obtain Starting Files

1. Right click on the zip file

2. Select Extract All...

3. Click Extract

4. The starting files are now available in a folder

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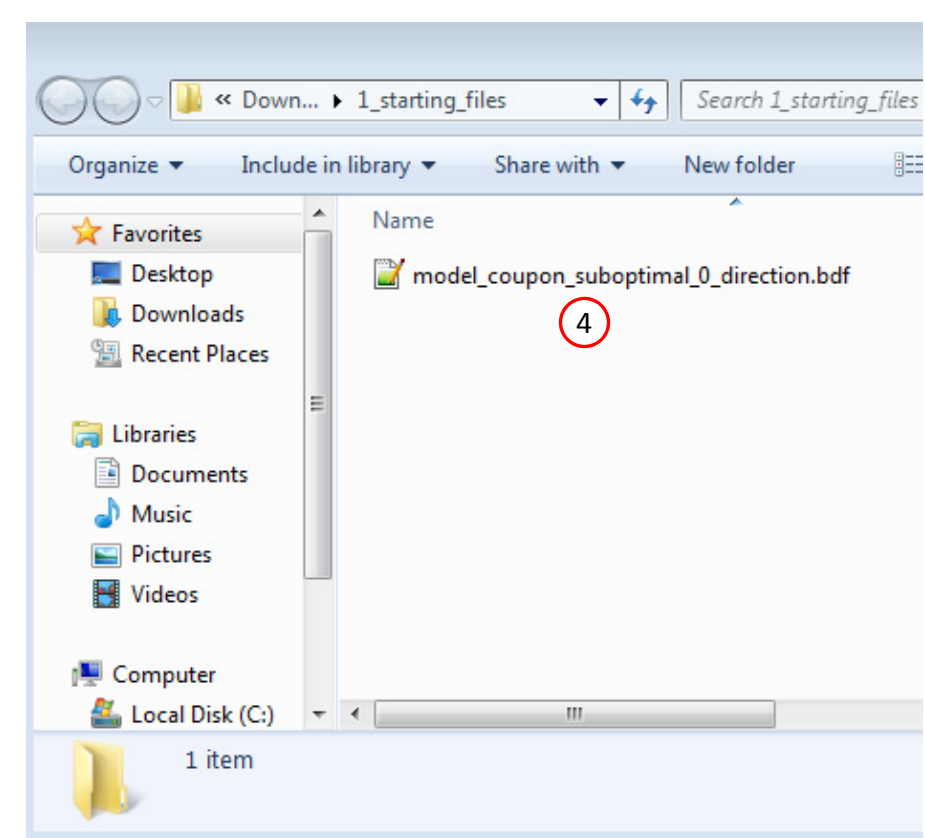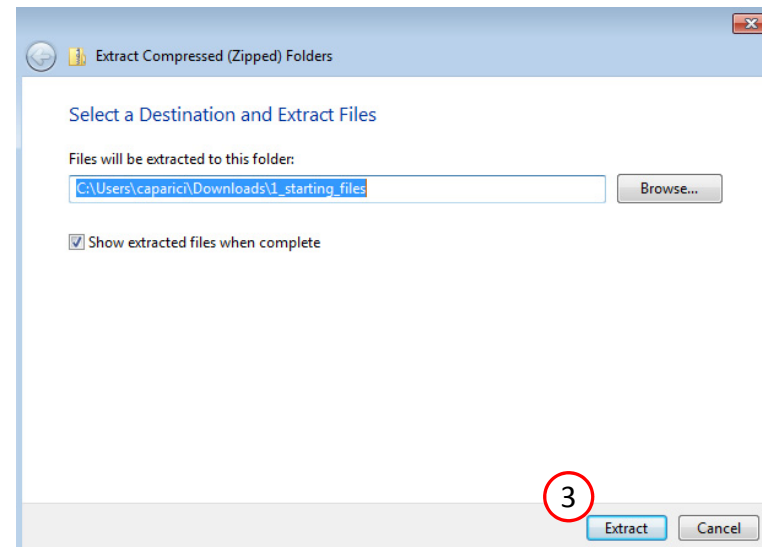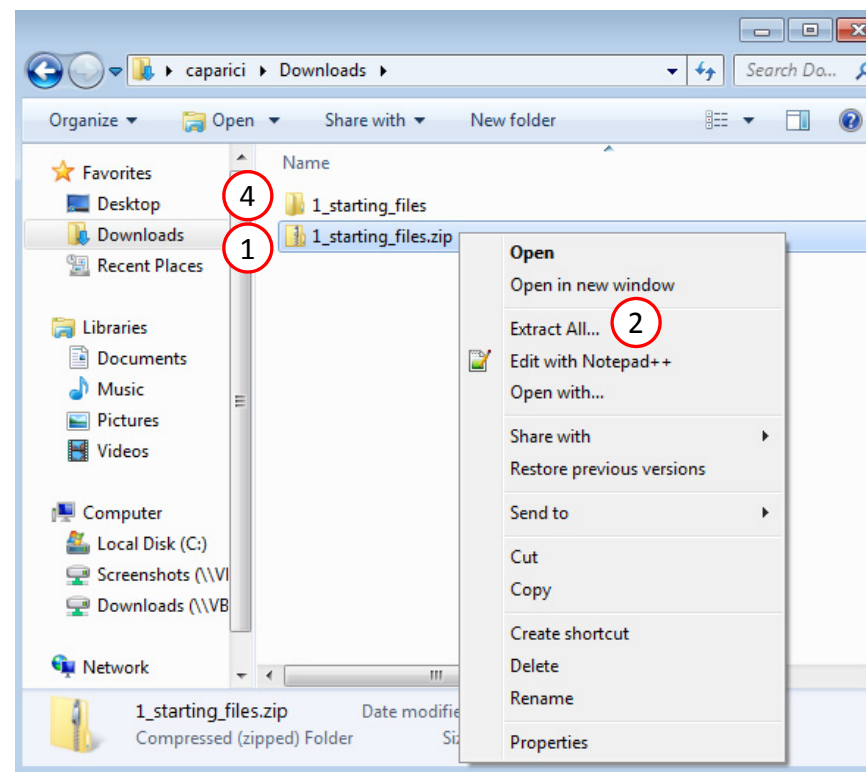
Open the Correct Page

1. Click on the indicated link

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

The Engineering Lab

SOL 200 Web App

Select a web app to begin

Optimization for SOL 200

Multi Model Optimization

Machine Learning | Parameter Study

HDF5 Explorer

Viewer

Tutorials and User's Guide

Full list of web apps

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Upload BDF Files

1. Click 1. Select Files and select model_coupon_suboptimal_0_direction.bdf

2. Click Upload Files

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

Step 1 - Upload .BDF Files

① 1. Select files   model_coupon_suboptimal_0_direction.bdf

Inspecting: 100%

② 2. Upload files

Uploading: 100 %

☐ List of Selected Files

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Create Design Variables

1. Click on the plus (+) icons to set the angle of layer 1 (THETA1) as design variable

2. A new variable x1 is created

3. Configure the following for variable x1
   1. Initial Value: 360.
   2. Lower Bound: 270.
   3. Upper Bound: 450.

- Recall that optimizers have difficulties when the variable approaches or takes on values of zero. Instead of working in the range of values from -90 to 90, the range is offset by +360 degrees to a new range of 270 and 450 degrees. After optimization, the final value of x1 is offset by -360 so that the value is back to the -90 and 90 range.

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

Size   Topology   Topometry   Topography

Step 1 - Select design properties

+ Options

Create DVXREL1	Property ⇕	Property Description ⇕	Entry ⇕	Entry ID ⇕	Current Value ⇕
	Search	Search	Search	Search	Search
➕	SB	Allowable shear stress of the bondin...	PCOMP	1	90.
➕	T1	Thickness of layer 1 (0°)	PCOMP	1	.125
① ➕	THETA1	Theta of layer 1 (0°)	PCOMP	1	0.
➕	T2	Thickness of layer 2 (0°)	PCOMP	1	3.175
➕	THETA2	Theta of layer 2 (0°)	PCOMP	1	0.

« 1 2 3 4 5 6 »   5 10 20 30 40 50

Step 2 - Adjust design variables

✖ Delete Visible Rows

+ Options

	Label ⇕	Status ⇕	Property ⇕	Property Description ⇕	Entry ⇕	Entry ID ⇕	Initial Value	Lower Bound	Upper Bound	Allowed Discrete Values
	Search	Search	Search	Search	Search	Search	Search	③	Search	Search
✖	x1	② ✔	THETA1	Theta of layer 1 (0°)	PCOMP	1	360.	270.	450.	Examples: -2.0, 1.0, THRU, 10.0,

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Create Design Objective

1. Click on Objective

2. Click on Equation Objective

- There are 2 methods of setting an objective.
  - Method 1 – Select a objective from a given list of responses, e.g. Weight, Volume, etc.
  - Method 2 – Create an equation.
- This example uses Method 2 for the objective.

Create Design Objective

1. Scroll down to section Step A - Optional - Create additional responses

2. Type in 'comp' to the search box

3. Click the plus (+) icon two times to create two compliance responses

4. Ensure compliance responses a1 and a2 have been created

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Create Design Objective

1. Scroll to section Step 1 - Adjust equation objective

2. Type this equation into the box
   - max(a1, a2)

- The objective is to maximize the stiffness of the model by varying the x-axis of the material coordinate system (0° direction). This is achieved by minimizing the compliance response and varying the angle of layer 1 on the PCOMP entry. Since there are multiple load cases in this example, you can either consider the compliance of the most critical load case, e.g. max(a1, a2), or you can consider the average compliance, e.g. avg(a1, a2).

Step 1 - Adjust equation objective ①

+ Options

Label	Status	Maximize or Minimize	②	Equation
R0	●	MIN ⌄	max(a1, a2)	

max(a1, a2)

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Assign Constraints to Load Cases (SUBCASES)

1. Click Subcases

2. Scroll to section: Step B - Optional - Configure DRSPAN for equation objective and constraints

3. Set a1 to SUBCASE 1

4. Set a2 to SUBCASE 2

- Response a1 is sourced from subcase 1 and response a2 is sourced from subcase 2.

Export New BDF Files

1. Click on Exporter

2. Click on Download BDF Files

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

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

BDF Output - Model

```
assign userfile = 'optimization_results.csv', status = unknown,
form = formatted, unit = 52
$ MSC.Nastran input file created on March     08, 2023 at 12:46:53 by
$ Patran 2022.2
$ Direct Text Input for Nastran System Cell Section
$ Direct Text Input for File Management Section
$ Direct Text Input for Executive Control
$ Linear Static Analysis, Database
SOL 200
CEND

SET 30001 = 6000001
SET 30002 = 6000002
ECHO = PUNCH(NEWBULK)
$ Direct Text Input for Global Case Control Data
   DESOBJ(MIN) = 9000000
   $ DESGLB Slot
   $ DSAPRT(FORMATTED, EXPORT, END=SENS) = ALL
SUBCASE 1
   ANALYSIS = STATICS
   DRSPAN = 30001
   $ DESSUB Slot
   SUBTITLE=Load Case 1
   SPC = 2
   LOAD = 2
   DISPLACEMENT(PLOT,SORT1,REAL)=ALL
   SPCFORCES(PLOT,SORT1,REAL)=ALL
   STRESS(PLOT,SORT1,REAL,VONMISES,BILIN)=ALL
$ Direct Text Input for this Subcase
```
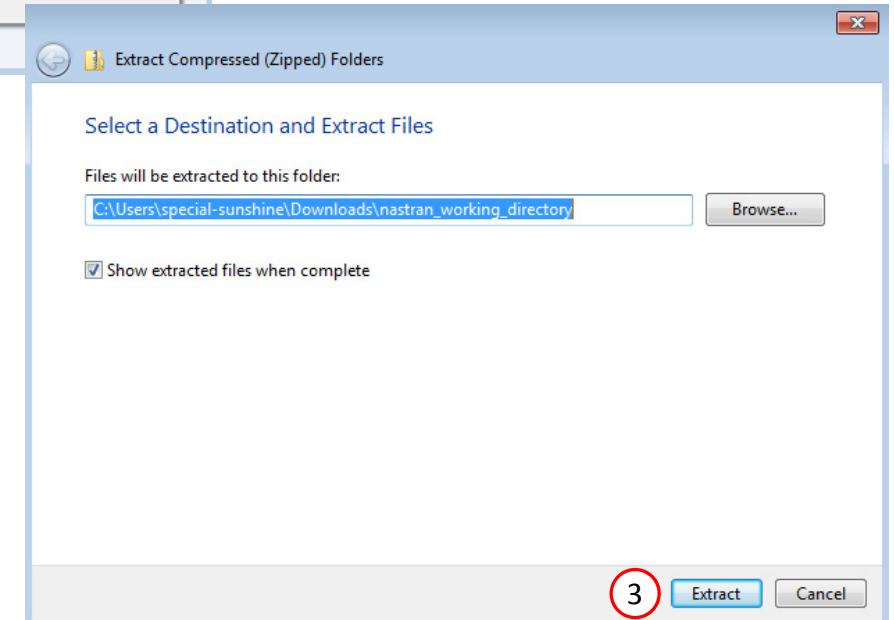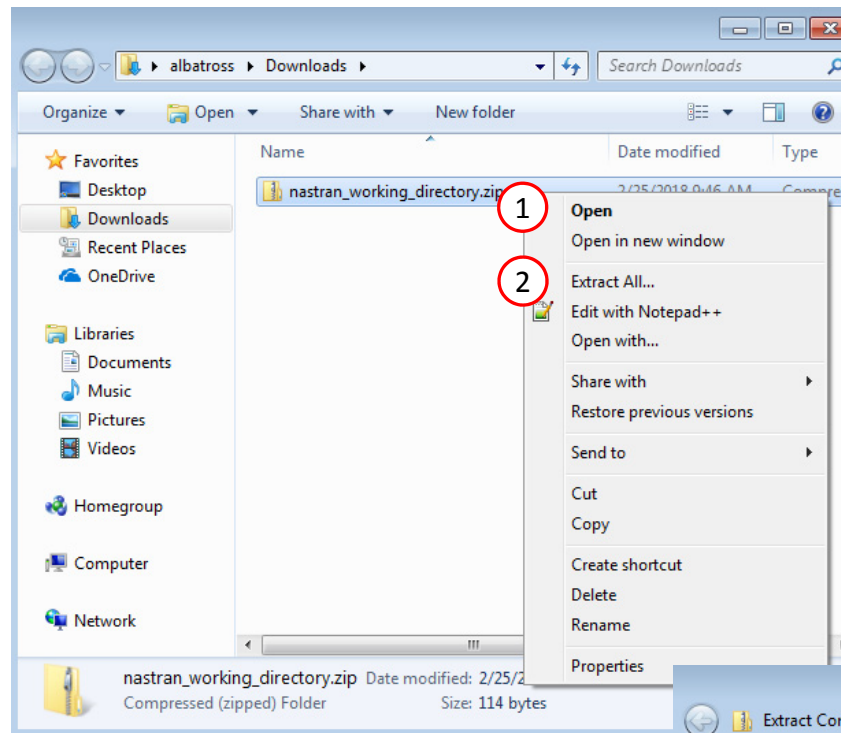
Download BDF Files

⬇ Download BDF Files   2

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Perform the Optimization with Nastran SOL 200

1. A new .zip file has been downloaded

2. Right click on the file

3. Click Extract All

4. Click Extract on the following window

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

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

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

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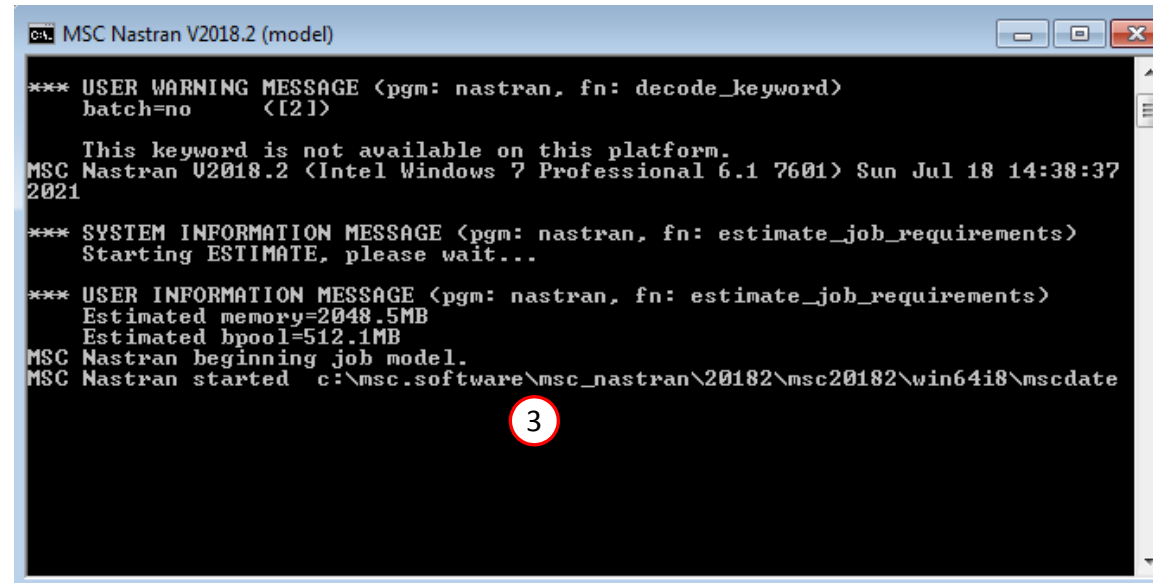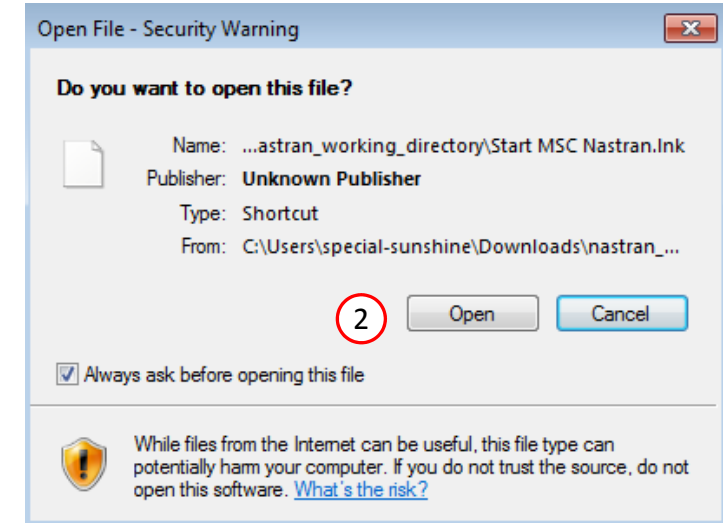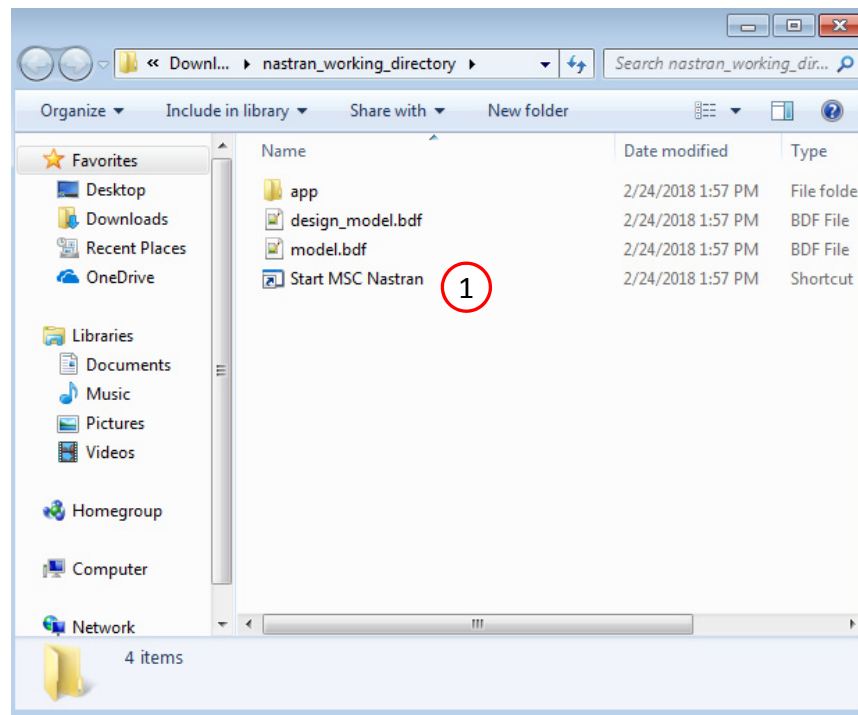
Status

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	

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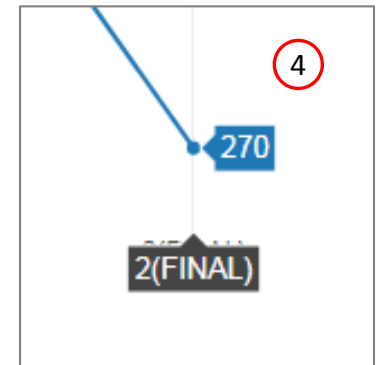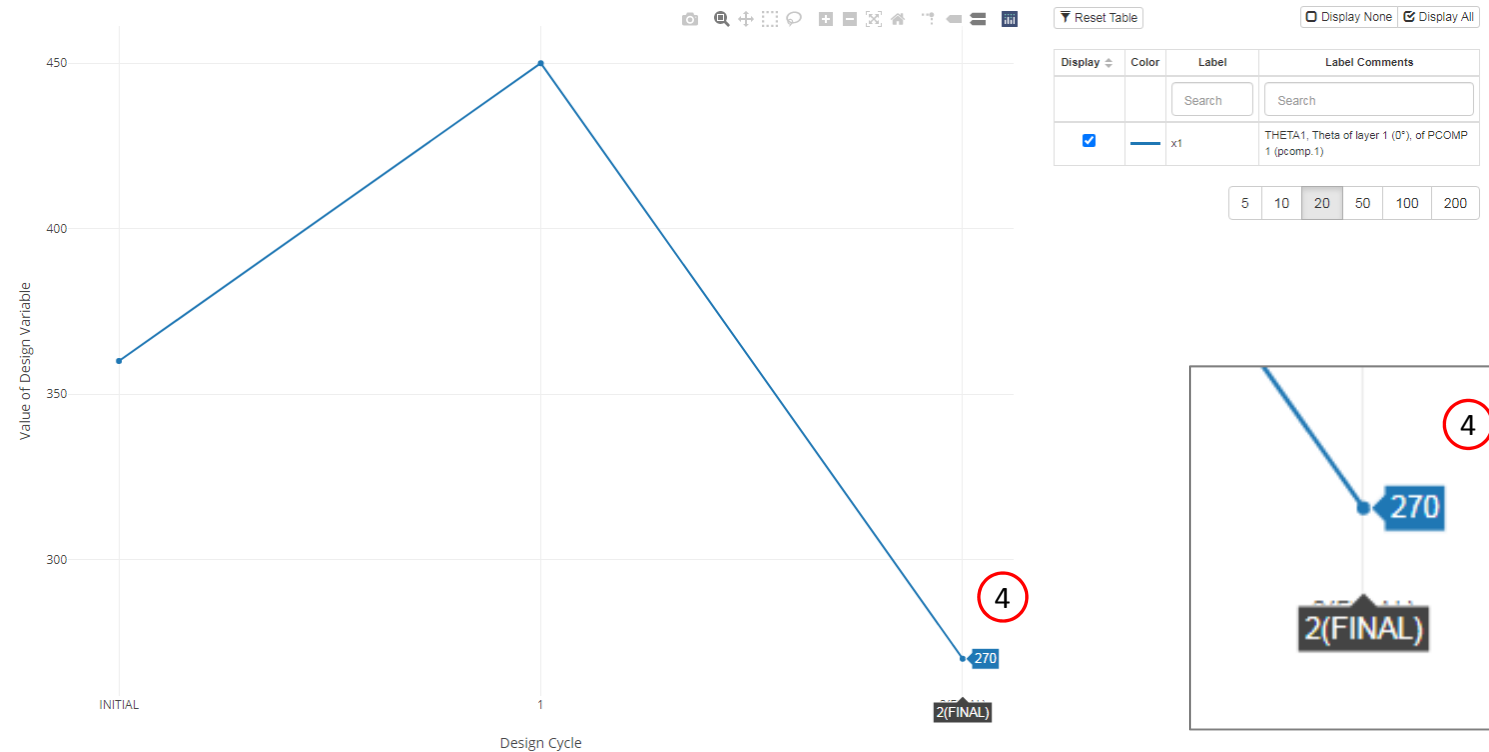
Review Optimization Results

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. Note that the compliance has been successfully minimized, i.e. the stiffness was maximized.

3. The final value of objective, normalized constraints (not shown) and design variables can be reviewed.

4. The final angle is 270°. Recall that the angle was offset by +360°. The angle 270° is offset by -360° to yield -90°. The x-axis of the material coordinate system should be rotated -90° to maximize the stiffness.

- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- If it is expected that multiple solutions may exist, it is recommended that multiple batch optimizations be configured with different initial values for x1, e.g. -75, -45, -25, 0, 25, 45, 75, or 285, 315, 335, 360, 385, 405, 435. The Machine Learning web app supports configuration of multiple batch runs.
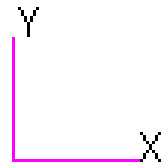
Final Message in .f06

1. ✓ RUN TERMINATED DUE TO HARD CONVERGENCE TO AN OPTIMUM AT CYCLE NUMBER = 2.

Objective

Design Variables

Display	Color	Label	Label Comments
		Search	Search
☑	—	x1	THETA1, Theta of layer 1 (0°), of PCOMP 1 (pcomp.1)

5 10 **20** 50 100 200
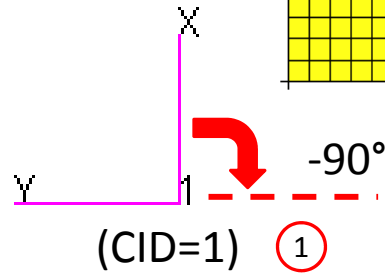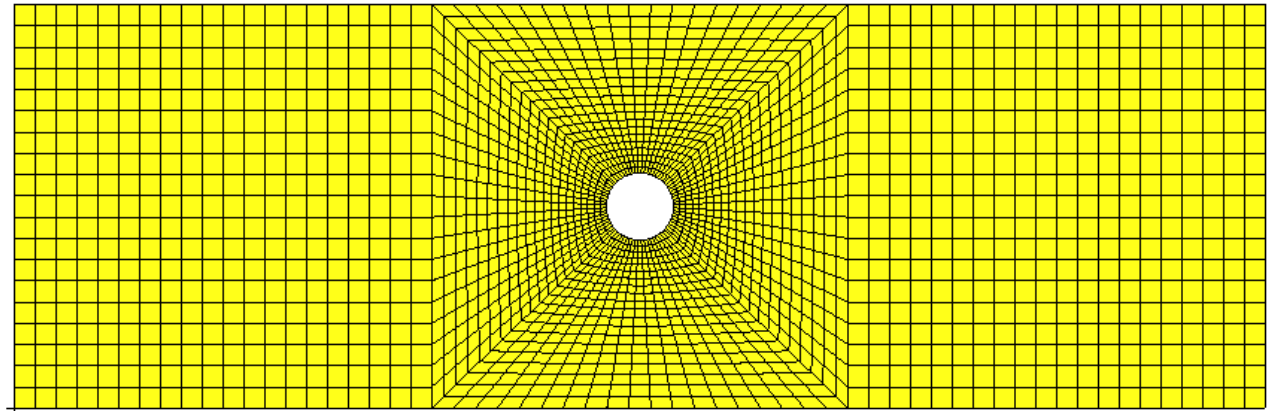
Discussion of Results

1. Coordinate system 1 must be rotated -90°

2. Notice that if CID=1 is rotated -90°, it will align with the default coordinate system (CID=0). CID=0 is used moving forward.

-90°

(CID=1) ①

Default Coordinate System (CID=0)

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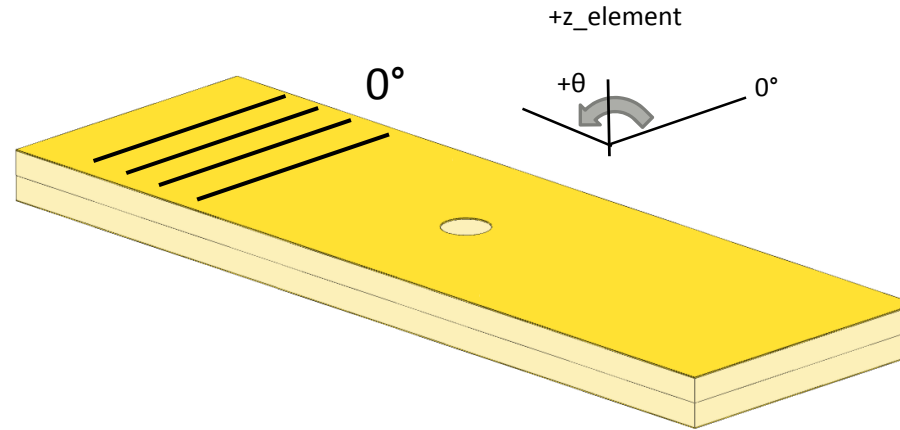
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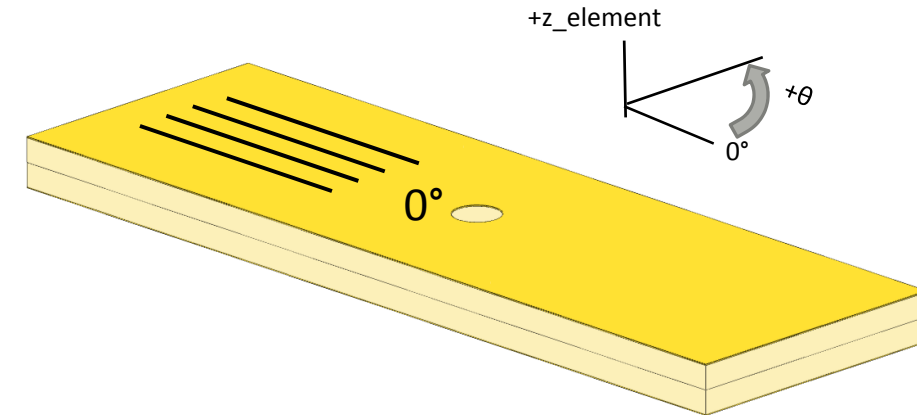
Discussion of Results

1. The 2D elements are updated to use CID=0, which was found to yield the best stiffness.

This concludes the determination of the optimal 0° direction.

Suboptimal 0° Direction

Optimal 0° Direction

Suboptimal 0° Direction

```
CQUAD4    1429      1          2393      2374      2452      2411        1           0.
CQUAD4    1430      1          2411      2452      2453      2410        1           0.
CQUAD4    1431      1          2410      2453      2454      2409        1           0.
[…]
```

1

Optimal 0° Direction

```
CQUAD4    1429      1          2393      2374      2452      2411        0           0.
CQUAD4    1430      1          2411      2452      2453      2410        0           0.
CQUAD4    1431      1          2410      2453      2454      2409        0           0.
[…]
```

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End of Tutorial